A STUDY ON USE OF WASTE POLYETHYLENE IN BITUMINOUS PAVING MIXES

A Thesis submitted in

Partial fulfilment of the requirements

For the award of the degree of

MASTER OF TECHNOLOGY

In

CIVIL ENGINEERING

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DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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CERTIFICATE

This is to certify that the thesis entitled "**A STUDY ON USE OF WASTE POLYETHYLENE IN BITUMINOUS PAVING MIXES**" submitted by **Monika Mohanty** bearing roll no. **211CE3244** in partial fulfilment of the requirements for the award of **Master of Technology** in **Civil Engineering** with specialization in "**Transportation Engineering"** during 2011-2013 session at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Bituminous mixes are most commonly used all over the world in flexible pavement construction. It consists of asphalt or bitumen (used as a binder) and mineral aggregate which are mixed together, laid down in layers and then compacted. Under normal circumstances, conventional bituminous pavements if designed and executed properly perform quite satisfactorily but the performance of bituminous mixes is very poor under various situations.

Today's asphaltic concrete pavements are expected to perform better as they are experiencing increased volume of traffic, increased loads and increased variations in daily or seasonal temperature over what has been experienced in the past. In addition, the performance of bituminous pavements is found to be very poor in moisture induced situations. Considering this a lot of work has been done on use of additives in bituminous mixtures and as well as on modification of bitumen. Research has indicated that the addition of polymers to asphalt binders helps to increase the interfacial cohesiveness of the bond between the aggregate and the binder which can enhance many properties of the asphalt pavements to help meet these increased demands. However, the additive that is to be used for modification of mix or binder should satisfy both the strength requirements as well as economical aspects.

Plastics are everywhere in today's lifestyle and are growing rapidly throughout particularly in a developing country like India. As these are non-biodegradable there is a major problem posed to the society with regard to the management of these solid wastes. Low density polyethylene (LDPE) has been found to be a good modifier of bitumen. Even, the reclaimed polyethylene originally made of LDPE has been observed to modify bitumen. In the present study, an attempt has been made to use reclaimed polyethylene which has been obtained from plastic packets used in packaging of a very popular brand of milk named OMFED, in dry form with the aggregates like a fibre in a bituminous mix. Detailed study on the effects of these locally waste polyethylene on engineering properties of Bituminous concrete (BC), Dense Bituminous macadam (DBM) and Stone mastic asphalt (SMA) mixes, has been made in this study.

The present locally available OMFED polyethylene used as stabilizer in SMA, BC and DBM mixes to fulfil the present requirements of paving mixes. Optimum binder content (OBC) and optimum polyethylene content (OPC) have been derived by using Marshall Procedure. The OBCs have been found to be 4% for SMA and 4.5% for both BC and DBM by using stone dust as filler. By replacing some gradation of fine aggregate by granulated blast furnace slag and fly ash as filler the OBCs have been found to be 5% of bitumen for SMA and 4% of bitumen for both BC and DBM mixes. Similarly, OPC has been found to be 2% by weight of mixes for SMA and DBM and 1.5% for BC mixes where stone dust has been used as filler. After replacement of some gradation of fine aggregate by slag and considering fly ash as filler the OPCs have been found to be 1.5% of polyethylene for all types of mixes. Then considering OBC and OPC, the SMA, BC, and DBM mixes have been prepared and different performance tests like Drain down test, Static indirect tensile Strength Test and Static Creep test have been carried out to evaluate the effects of polyethylene as an stabilizer on mix properties. It is concluded from present investigation that addition of OMFED Polyethylene to mixes improve the mix properties like Marshall Stability, Drain down characteristics and indirect tensile strength.

Key Words: Bituminous concrete (BC), Stone mix asphalt (SMA), Dense bound macadam (DBM), OMFED polyethylene, Marshall Properties, Static indirect tensile strength, and Static creep Test

CONTENTS

LIST OF THE TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HMA	Hot mix asphalt
SMA	Stone mastic asphalt
BC	Bituminous concrete
DBM	Dense bound macadam
SMAWP	Stone mastic asphalt with polyethylene
BCWP	Bituminous concrete with polyethylene
DBMWP	Dense bound macadam with polyethylene
SMAFS	Stone mastic asphalt with fly ash and slag
BCFS	Bituminous concrete with fly ash and slag
DBMFS	Dense bound macadam with fly ash and slag
SMAFSWP	Stone mastic asphalt with fly ash, slag and polyethylene
BCFSWP	Bituminous concrete with fly ash, slag and polyethylene
DBMFSWP	Dense bound macadam with fly ash, slag and polyethylene
HDPE	High density polyethylene
LDPE	Low density polyethylene
PET	Polyethylene Terephthalate
EVA	Ethylene-vinyl acetate
FAUP	Fly Ash Utilisation Programme
GBFS	Granulated blast furnace slag
MORTH	Ministry of Road Transport & Highways
DSC	Differential scanning calorimeter
OBC	Optimum Binder Content
OPC	Optimum polyethylene content

ITS	Indirect tensile strength test
TSR	Tensile strength ratio
VA	Air void
VMA	Void in mineral aggregates
VFB	Void filled with bitumen

LIST OF SYMBOLS

G_{Sb} Bulk specific gravity of aggregate

G_{se} Effective specific gravity of aggregate

M_b Mass of bitumen used in mix

G_b Specific gravity of bitumen

G_a Apparent specific gravity

G_{mm} Theoretical maximum specific gravity of mix

G_{mb} Bulk specific gravity of mix

P_S Percentage of aggregate present by total mass of mix

S_T Indirect Tensile Strength

S_2 Soaked stability

S_1 Standard stability

W_1 Initial mass of the plate

W_2 Final mass of the plate and drained binder

CHAPTER 1

INTRODUCTION

1.1 General

Bituminous binders are widely used by paving industry. In general pavements are categorized into 2 groups, i.e. flexible and rigid pavement.

Flexible Pavement

Flexible pavements are those, which on the whole have low flexural strength and are rather flexible in their structural action under loads. These types of pavement layers reflect the deformation of lower layers on-to the surface of the layer.

Rigid Pavement

If the surface course of a pavement is of Plain Cement Concrete then it is called as rigid pavement since the total pavement structure can't bend or deflect due to traffic loads.

Pavement design and the mix design are two major considerations in case of pavement engineering. The present study is only related to the mix design of flexible pavement considerations. The design of asphalt paving mixtures is a multi-step process of selecting binders and aggregate materials and proportioning them to provide an appropriate compromise among several variables that affect mixture behaviour, considering external factors such as traffic loading and climate conditions.

1.2 Bituminous mix design

1.2.1 Overview

The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical. There are two types of the mix design, i.e. dry mix design and wet mix design.

1.2.2 Objective of Bituminous mix design

Main objectives of bituminous mix design are to find;

1. Optimum bitumen content to ensure a durable pavement,
2. Sufficient strength to resist shear deformation under traffic at higher temperature,
3. Proper amount of air voids in the compacted bitumen to allow for additional compaction done by traffic,
4. Sufficient workability, and
5. Sufficient flexibility to avoid cracking due to repeated traffic load.

1.2.3 Requirements of bituminous mixes

Bituminous mixture used in construction of flexible pavement should have following properties;

1. Stability
2. Durability
3. Flexibility
4. Skid resistance
5. Workability

1.2.4 Different layers in a pavement

- Bituminous base course Consist of mineral aggregate such as stone, gravel, or sand bonded together by a bituminous material and used as a foundation upon which to place a binder or surface course.
- In bituminous binder course a bituminous-aggregate mixture is used as an intermediate course between the base and surface courses or as the first bituminous layer in a two-layer bituminous resurfacing.
- Asphaltic/Bituminous concrete consists of a mixture of aggregates continuously graded from maximum size , typically less than 25 mm, through fine filler that is smaller than 0.075 mm. Sufficient bitumen is added to the mix so that the compacted mix is effectively impervious and will have acceptable dissipative and elastic properties.

1.2.5 Types of bituminous mix

Dense-Graded Mixes

Dense mix bituminous concrete has good proportion of all constituents. It offers good compressive strength and some tensile strength.

Gap-graded mix

Some large coarse aggregates are missing and have good fatigue and tensile strength.

Open-graded mix

Fine aggregate and filler are missing; it is porous and offers good friction, low strength.

Hot mix asphalt concrete

HMA is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at 150 °C for virgin asphalt.

Warm mix asphalt

It is produced by adding zeo-lites waxes, asphalt emulsions, or sometimes even water to the asphalt binder prior to mixing. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon dioxide, aerosols and vapours.

Cold mix asphalt

It is produced by emulsifying the asphalt in water with prior to mixing with the aggregate. It results less viscous asphalt and the mixture is easy to work and compact. The emulsion breaks after evaporation of water and the cold mix asphalt ideally behaves as cold HMA.

Cut-back asphalt concrete

It is produced by dissolving the binder in kerosene or another lighter fraction of petroleum which makes asphalt less viscous and the mix is easy to work and compact. After the mix is laid down the lighter fraction evaporates. Because of concerns with pollution from the volatile organic compounds in the lighter fraction, cut-back asphalt has been largely replaced by asphalt emulsion.

Mastic asphalt concrete

Mastic asphalt is produced by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has become a viscous liquid before it is added to aggregates. Then bitumen aggregate mixture is cooked (matured) for around 6-8 hours and once it is ready the mastic asphalt mixer is transported to the work site where it generally laid to a thickness of around 3⁄4–13⁄16inches(20-30 mm) for footpath and road applications and around 3⁄8 of an inch (10 mm) for flooring or roof applications.

1.3 Polymer modification

1.3.1 Present Scenario

Bituminous binders are widely used in road paving and their viscoelastic properties are dependent on their chemical composition. Now-a-days, the steady increment in high traffic intensity in terms of commercial vehicles, and the significant variation in daily and seasonal temperature put us in a situation to think about some alternative ways for the improvement of the pavement characteristics and quality by applying some necessary modifications which shall satisfy both the strength as well as economical aspects. Bitumen can also be modified by adding different types of additives to achieve the present requirement. One of these additives is the polymers.

1.3.2 Waste plastic: the problem

Today availability of plastic waste is enormous. The use of plastic materials such as carry bags, cups, etc is constantly increasing. Nearly 50% to 60% of total plastic are consumed for packing. Once used, plastic packing materials are thrown outside and they remain as waste. Plastic wastes are durable and non-biodegradable. The improper disposal of plastic may cause breast cancer, reproductive problems in humans and animals, genital abnormalities and much more. These plastic wastes get mixed with water, disintegrate, and take the forms of small pallets which cause the death of fishes and other aquatic life who mistake them as food material. Sometimes they are either land filled or incinerated. Plastic wastes get mixed with the municipal solid waste or thrown over a land area. All the above processes are not eco-friendly as they pollute the land, air and water. Under these circumstances, an alternative use of these plastic wastes is required. So any method that can use this plastic waste for purpose of construction is always welcomed.

1.3.3 Role of polyethylene in bituminous pavements

Use of polyethylene in road construction is not new. Some aggregates are highly hydrophilic (water loving). Like bitumen polyethylene is hydrophobic (water hating) in nature. So the addition of hydrophobic polymers by dry or wet mixing process to asphalt mix lead to improvement of strength, water repellent property of the mix. Polyethylenes get added to hot bitumen mixture and the mixture is laid on the road surface like a normal tar road. Plastic roads mainly use plastic carry-bags, disposable cups, polyethylene packets and PET bottles that are collected from garbage as important ingredients of the construction material. Polymer modification can be considered as one of the solution to improvise the fatigue life, reduce the rutting & thermal cracking in the pavement. Creating a modified bituminous mixture by using recycled polymers (e.g., polyethylene) which enhances properties of HMA mixtures would not only produce a more durable pavement, but also provide a beneficial way of disposal of a large amount of recycled plastics.

1.4 Objectives of present investigation

A comparative study has been made in this investigation between SMA, BC, and DBM mixes with varying binder contents (3.5% - 7%) and polyethylene contents (0.5% - 2.5%).

The objectives of this investigation are to observe the followings;

- Study of Marshall properties of mixes using both
    1. Stone dust as filler and,
    2. Slag as fine aggregate and fly ash as filler.
- The effect of polyethylene as admixture on the strength of bituminous mix with different filler and replacing some percentage of fine aggregate by slag.

- The performance of bituminous mix under water with and without polyethylene admixture with different filler and replacing some percentage of fine aggregate by slag.
- To study resistance to permanent deformation of mixes with and without polyethylene.
- Evaluation of SMA, BC, and DBM mixes using different test like Drain down test, Static Indirect tensile Strength test, Static Creep test etc.

1.5 Organization of Thesis

The thesis consists of six chapters as described below:

- Chapter 1 describes general idea about flexible pavement, its performance characteristics, present scenario, and utilization of polyethylene in achieving present requirement.
- Chapter 2 deals with a review of previous work on laboratory studies.
- Chapter 3 explains the material used in present investigation.
- Chapter 4 deals with experimental investigation.
- Analysis of the results and discussion on the experimental investigations is discussed in Chapter 5.
- Conclusions and scope for future scope of this work is summarized in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Studies on polyethylene

1. IPC, Institute for Interconnecting and Packaging Electronic Circuits (1995) published a test manual for determining the tensile strength, elongation and Young's modulus of organic free films by using ASTM D 618, ASTM D 882, ASTM D 1005 and ASTM D 2370.
2. Sichina et al. Characterized Polymers Using TGA (thermo gravity analysis). According to him TGA measures the amount and rate of change in the mass of a sample as a function of temperature or time in a controlled atmosphere to determine the thermal and/or oxidative stabilities of materials as well as their compositional properties. It is especially useful for the study of polymeric materials, including thermoplastics, thermo-sets, elastomers, composites, films, fibers, coatings and paints.

2.2 Studies on Use of waste polyethylene in paving mixes

1. Bindu and Beena (2010) studied how Waste plastic acts as a stabilizing additive in Stone Mastic Asphalt when the mixtures were subjected to performance tests including Marshall Stability, tensile strength, compressive strength tests and Tri-axial tests. There results indicated that flexible pavement with high performance and durability can be obtained with 10% shredded plastic.
2. Fernandes et al. (2008) studied Rheological evaluation of polymer modified asphalt binders by using thermoplastic elastomer styrene butadiene styrene (SBS) and they compared the properties of Modified binder by addition of both oil shale and aromatic

oil to improve their compatibly. The rheological characteristics of the SBS PMBs were analyzed in a dynamic shear rheometer (DSR) and the morphology accessed by fluorescence optical microscopy. The results indicated that the aromatic and shale oils have similar effects on the microstructure, storage stability and viscoelastic behaviour of the PMBs. Thus, shale oil could be successfully used as a compatibilizer agent without loss of properties or could even replace the aromatic oil.

3. Awwad and Shbeeb (2007) indicated that the modified mixture has a higher stability and VMA percentage compared to the non-modified mixtures and thus positively influence the rutting resistance of these mixtures. According to them modifying asphalt mixture with HDPE polyethylene enhances its properties far more than the improvements realized by utilizing LDPE polyethylene.
4. Gawande et al. (2012) gave an overview on waste plastic utilization in asphalting road by using both wet and dry method. They said that use of modified bitumen with the addition of processed waste plastic of about 5-10% by weight of bitumen helps in improving the longevity and pavement performance with marginal saving in bitumen usage and according to them use of waste plastics in the manufacture of roads and laminated roofing also help to consume large quantity of waste plastics. Thus, these processes are socially highly relevant, giving better infrastructure.
5. Khan and Gundaliya (2012) stated that the process of modification of bitumen with waste polythene enhances resistance to cracking, pothole formation and rutting by increasing softening point, hardness and reducing stripping due to water, thereby improving the general performance of roads over a long period of time. According to them the waste polythene utilized in the mix forms coating over aggregates of the mixture which reduces porosity, absorption of moisture and improves binding property.

6. Prusty (2012) studied the behaviour of BC mixes modified with waste polythene. He used various percentages of polythene for preparation of mixes with a selected aggregate grading as given in the IRC Code. Marshall Properties such as stability, flow value, unit weight, air voids are used to determine optimum polythene content for the given grade of bitumen (80/100) in his study. Considering these factors he observed that a more stable and durable mix for the pavements can be obtained by polymer modifications.
7. Swami et al. (2012) investigated that the total material cost of the project is reduced by 7.99% with addition of plastic to bitumen between the ranges of 5% to 10%. They concluded that by modification of bitumen the problems like bleeding in hot temperature regions and sound pollution due to heavy traffic are reduced and it ultimately improves the quality and performance of road.
8. Pareek et al. (2012) carried out experimental study on conventional bitumen and polymer modified binder and observed a significant improvement in case of rutting resistance, indirect tensile strength and resilient modulus of the bituminous concrete mix with polymer modified bitumen. They also concluded that Polymer modified bitumen results a high elastic recovery (79%) and better age resistance properties (The loss in weight on heating in thin film oven is 6 times higher as compared to conventional bitumen of 60/70).
9. Sangita et al. (2011) suggested a novel approach to improve road quality by utilizing plastic waste in road construction. According to them India spends Rs 35,000 crores a year on road construction and repairs, including Rs 100,000 crores a year just on maintenance and roads by bitumen modification lasts 2-3 times longer, which will save us Rs 33,000 crores a year in repairs, plus reduced vehicle wear and tear.

10. Sabina et al. (2009) evaluated the performance of waste plastic/polymer modified bituminous mix and observed that the results of marshal stability and retained stability of polythene modified bituminous concrete mix increases 1.21 and 1.18 times higher than that of conventional mix by using 8% and 15% (by weight of bitumen) polythene with respect to 60/70 penetration grade of bitumen. But modified mix with 15% polyethylene showed slightly decreased values for Marshall Stability than that of the mix with 8% modifier in their results.
11. Reinke and Glidden (2002) tested the resistance of HMA mixtures to failure by using the DSR (dynamic shear rheometer) creep and recovery tests and reported that result shows improved resistance in case of polymer modified binders.
12. Karim et al. gave a potential solution to strength loss of bituminous pavement under water. They compared performance of bituminous mix under water with and without polyethylene admixture and conclude that bitumen mixes with polyethylene performed well under water and showed even better Marshall Stability than normal bituminous mix under normal condition Keeping the environment safe from pollution will be an added bonus.
13. Yousefi (2009) stated that the polyethylene particles do not tend to rip in bitumen medium and these particles prefer to join together and form larger particles due to interfacial and inter-particle attractive forces and the only obstacle in the modification process was the existence of partitions made from molten bitumen. According to the author whenever, particles had enough energy to come close together and overcome the thin remained bitumen film which was separating particles, the coalescence of polyethylene particles occurred and lead to polymer phase separation.
14. Vasudevan (2004) utilized polythene/polypropylene Bags for integrated development of Rural and Arterial road network for socio-economic Growth. He studied both dry

and wet mixing process by adding polymer with respect to the weight of bitumen used. Author reported that polymer bitumen blend is a better binder compared to plain bitumen resulting higher Marshall Stability and decreasing the possibilities of pot-holes formation.

15. Verma (2008) studied that plastic increases the melting point of the bitumen and makes the road flexible during winters resulting in its long life. According to author while a normal “highway quality” road lasts four to five years, plastic-bitumen roads can last up to 10 years and it would be a boon for India’s hot and extremely humid climate, where temperatures frequently cross 50°C and torrential rains create havoc, leaving most of the roads with big potholes.
16. Moghaddam and Karim (2012) reported that the utilization of waste material in asphalt pavement would be beneficial in order to find an alternative solution to increase service life of asphalt pavement and reduce environmental pollution as well. Form their study it is concluded that Polyethylene Terephthalate (PET) reinforced mixtures possess higher stability value, flow, fatigue life in comparison with the mixtures without PET.
17. Wegan and Nielsen (2001) studied microstructure of polymer modified binders in bituminous mixtures by preparing thin sections of the specimen and analysing that thin section by Infrared Fourier Transform Spectrometer. When thin sections were illuminated with the UV-light, the polymer phase emits yellow light, fine and coarse aggregates often appear green, the bitumen phase is black and air voids or cracks appear with a yellow-green colour.
18. Herndon (2009) investigated moisture susceptibility of asphalt mixture using phosphonylated recycled polythene. They indicated that there is a significant reduction in moisture susceptibility with the addition of recycled unmodified

polyethylene to asphalt concrete mixtures in both the Wet Process and the Dry Process.

19. Jain et al. (2011) studied mitigation of rutting in bituminous roads by use of waste polymeric packaging materials and concluded that rutting of bituminous mix can be reduced to 3.6 mm from a value of 16.2 mm after application of 20,000 cycles, by adding optimum quantity of polyethylene in bituminous mix for road construction, ultimately improves pavement performance, besides alleviating disposal problems of WPPM for clean and safe environment.
20. Firoozifar et al. (2010) investigated the novel methods to improve the storage stability and low temperature susceptibility of polythene modified bitumen. They used Kerosene, Oleic Acid, Aromatic oil, B-oil etc for increasing stability of polythene modified bitumen and a fluorescent microscope to observe the homogeneity of the samples.
21. Aslam and Rahman (2009) studied both dry and wet mix and concluded that the dry process is more economical and beneficial for construction of flexible pavements. Because in case of higher percentage of polythene in wet process they get separate out from bitumen on cooling, so it needs some additives.
22. ScienceTech Entrepreneur (2008) propossed that the durability of the roads laid with shredded plastic waste is much more compared with those which asphalted with the ordinary mix. While a normal highway road lasts 4 to 5 years it is claimed in this paper that plastic-bitumen roads can last up to 10 years. According to this paper rainwater will not seep through because of the plastic in the tar. So, this technology will result in lesser road repairs.

23. The Indian Roads Congress Specifications Special Publication: 53 (2002) indicate that the time period of next renewal may be extended by 50% in case of surfacing with modified bitumen as compared to unmodified bitumen.
24. Habib et al. studied rheological properties of bitumen modified by thermoplastic namely linear low density polyethylene (LLDPE), high density polyethylene (HDPE) and polypropylene (PP) and its interaction with 80 penetration grade of bitumen through penetration test, ring & ball softening point and viscosity test. It was observed that thermoplastic copolymer shows profound effect on penetration rather than softening point. According to author Visco-elastic behaviour of polymer modified bitumen depend on the concentration of polymer, mixing temperature, mixing technique, solvating power of base bitumen and molecular structure of polymer used and PP offer better blend in comparison to HDPE and LLDPE.
25. Punith and Veeraragavan studied Behavior of Asphalt Concrete Mixtures with reclaimed polyethylene as additive. The dynamic creep test (unconfined), indirect tensile test, resilient modulus test, and Hamburg wheel track tests were carried out in their investigation on blend of PE (2.5, 5.0, 7.5, and 10% by weight of asphalt) with (80/100) paving grade asphalt and observed that the rutting potential and temperature susceptibility can be reduced by the inclusion of PE in the asphalt mixture.
26. Sui and Chen (2011) studied application and performance of polyethylene as modifying additive in asphalt mixture. They added polyethylene as additive to hot mineral aggregate for few minutes, and then added the asphalt mixing together which simplifies the construction process and reduces the cost of construction. They concluded that there is improvement on high temperature stability, low temperature cracking resistance and water resistance on modification and evaluate polyethylene as additive in the technical, economic and environmental aspects.

27. Casey et al. (2008) studied the development of a recycled polymer modified binder for use in stone mastic asphalt. From their study it was found that the addition of 4% recycled HDPE into a pen grade binder produced the most promising results, and results obtained from wheel track and fatigue tests show that although the binder does not deliver equivalent performance means dose not perform to the same high levels as a proprietary polymer modified binder, it does out-perform traditional binders used in stone mastic asphalt.
28. Al-Hadidy and Yi-qiu (2009) investigated the potential use of pyrolysis a low density polyethylene (LDPE) as a modifier for asphalt paving materials. Their research results indicate that modified binders show higher softening point, keeping the values of ductility at minimum range of specification of (100+ cm), and cause a reduction in percentage loss of weight due to heat and air (i.e. increase durability of original asphalt).
29. Attaelmanan et al. (2011) carried out Laboratory evaluation of HMA with high density polyethylene as a modifier. The analyses of test results show that the performance of HDPE-modified asphalt mixtures are better than conventional mixtures because the moisture susceptibility and temperature susceptibility can be reduced by the inclusion of HDPE content of 5% by weight of asphalt in the conventional asphalt mixture. They also carried out drain down, Marshall, indirect tensile strength, flexural strength and resilient modulus tests and got positive results in each cases.
30. Ahmadinia et al. (2012) carried out an experimental research on the application of waste plastic bottles (Polyethylene Terephthalate (PET)) as an additive in stone mastic asphalt (SMA). Wheel tracking, moisture susceptibility, resilient modulus and drain down tests were carried out in their study on the mixtures that included various

percentages of waste PET as 0%, 2%, 4%, 6%, 8% and 10% by weight of bitumen content. Their results show that the addition of waste PET into the mixture has a significant positive effect on the properties of SMA which could improve the mixture's resistance against permanent deformation (rutting), increase the stiffness of the mix, provide lower binder drain down and promotion of re-use and recycling of waste materials in a more environmentally and economical way.

31. Vargas et al. (2013) analysed the chemically-grafted polyethylene as asphalt modifiers. Their results show that the softening point of asphalt increased, while the penetration degree decreased in blends prepared with grafted polyethylene and the phase distributions of micrographs from fluorescence microscopy show that non-grafted polyethylene polymers were not readily miscible with asphalt. The results of rheological tests carried out in their study indicate that most of asphalt blends exhibit improved performance at higher temperature with grafted polyethylene such as enhancing rutting resistance, flow activation energy and superior time–temperature-dependent response as compared to the reference polyethylene blends.
32. Rahman and Wahab (2013) used recycled polyethylene terephthalate (PET) as partial replacement of fine aggregate in modified asphalt in their investigation. In term of economic value, it shows that this recycled PET could reduce cost of road construction because this recycled material is cheaper than bitumen and easy to obtain, which also improves the level of performance and the service life of the road. It can be concluded from their study that the application of recycled PET modified asphalt gives more advantages compared to the conventional asphalt mixture especially in term of permanent deformation.
33. Panda and Mazumdar (2002) utilized reclaimed polyethylene (PE) obtained from LDPE carry bags to modify asphalt cement. They studied the basic properties such as

Marshall stability, resilient modulus, fatigue life, and moisture susceptibility of mixes with 2.5% of PE and compared with those of asphalt cement. They concluded that at a particular temperature and stress level, polymer modification increases the resistance to moisture susceptibility, resilient modulus and fatigue life of mixes.

34. Denning and Carswell (1981) used NOVOPHALT binder which is Austrian asphalt (B70) modified with 7% by weight of PE. They have suggested that higher mixing and laying temperatures will be required for mixtures containing NOVOPHALT and reported that asphalt concrete using polyethylene modified binders were more resistant to permanent deformation at elevated temperature.
35. Airey et al. (2004) studied Linear Rheological behaviour of bituminous paving materials. They concluded that the rheological behaviour of asphalt mixtures incorporating a range of unmodified and modified binders showed similarities to the rheological characteristics of the constituent RTFOT aged binders and the stiffening effect of the DBM asphalt mixture for both the unmodified and SBS modified binders was found to be approximately 100 times greater at high complex modulus values and approximately 6,000 times greater at low complex modulus values.
36. Murphy et al. (2001) examined the possibility of incorporating waste polymer into bitumen as a modifier, evaluated the performance of recycled modified bitumen and compare their properties with those of standard bitumen and polymer modified bitumen. They concluded polypropylenes are not useful in improving the properties of bitumen and displayed practical difficulties during mixing and testing, suggesting poor cohesion with bitumen.
37. Panda and Mazumdar (1999) studied the engineering properties of EVA-modified bitumen binder for paving mixes and found that 5% EVA concentration in modified binder by weight is adequate to enhance the properties. They observed that the

penetration, ductility, and specific gravity of the modified binders decrease as compared with unmodified bitumen while the softening point temperature, temperature susceptibility and viscosity increase.

CHAPTER 3

RAW MATERIALS

3.1 Constituents of a mix

Bituminous mix consists of a mixture of aggregates continuously graded from maximum size, typically less than 25 mm, through the fine filler that is smaller than 0.075mm. Sufficient bitumen is added to the mix so that the compacted mix is effectively impervious and will have acceptable dissipative and elastic properties. The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical.

The basic materials used are as follows:

- Aggregates
- Fly Ash
- Slag
- Bituminous Binder
- Polyethylene

3.1.1 Aggregates

There are various types of mineral aggregates used to manufacture bituminous mixes can be obtained from different natural sources such as glacial deposits or mines and can be used with or without further processing. The aggregates can be further processed and finished to achieve good performance characteristics. Industrial by-products such as steel slag, blast furnace slag, fly ash etc. sometimes used by replacing natural aggregates to enhance the performance characteristics of the mix. Aggregate contributes up to 90-95 % of the mixture weight and contributes to most of the load bearing & strength characteristics of the mixture.

Hence, the quality and physical properties of the aggregates should be controlled to ensure a good pavement. Aggregates are of 3 types;

Coarse aggregates

The aggregates retained on 4.75 mm sieve are called as coarse aggregates. Coarse aggregate should be screened crushed rock, angular in shape, free from dust particles, clay, vegetations and organic matters which offer compressive and shear strength and shows good interlocking properties. In present study, stone chips are used as coarse aggregate with specific gravity 2.75.

Fine aggregates

Fine aggregate should be clean screened quarry dusts and should be free from clay, loam, vegetation or organic matter. Fine aggregates, consisting of stone crusher dusts were collected from a local crusher with fractions passing 4.75 mm and retained on 0.075 mm IS sieve. It fills the voids in the coarse aggregate and stiffens the binder. In this study, fine stones and slag are used as fine aggregate whose specific gravity has been found to be 2.6 and 2.45.

Filler

Aggregate passing through 0.075 mm IS sieve is called as filler. It fills the voids, stiffens the binder and offers permeability. In this study, stone and fly ash are used as filler whose specific gravity has been found to be 2.7 and 2.3.

3.1.2 Fly Ash

At present, as per the report of the Fly Ash Utilisation Programme (FAUP), out of the huge quantity of fly ash produced, only about 35% finds its use in commercial applications such as mass concrete, asphalt paving filler, lightweight aggregate, stabilizer to road bases, raw material for concrete, additives to soil, construction of bricks etc. The remainder fly ash is a waste requiring large disposal area, causing a huge capital loss to power plants and simultaneously causing an ecological imbalance and related environmental problems (Dhir, 2005). In this investigation fly ash is used as one type of filler.

3.1.3 Granulated blast furnace slag

Granulated blast furnace slag (GBFS) is a by-product obtained in the manufacture of pig iron in the blast furnace and is formed by the combination of iron ore with limestone flux. If the molten slag is cooled and solidified by rapid water quenching to a glassy state, it results granulated blast furnace slag of sand size fragments, usually with some friable clinker- like material. The physical structure and gradation of granulated slag depend on the presence of chemicals such as lime, alumina, silica and magnesia, whose percentages may vary depending on the nature of iron ore, the composition of limestone flux and the kind of iron being produced. In present study granulated blast furnace slag is used as fine aggregates by replacing some gradation of natural aggregates.

3.1.4 Bituminous Binder

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Bitumen must be treated as a visco-elastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. At low temperature it behaves like an elastic material and at high temperatures its behaviour is like a viscous fluid. Asphalt binder VG30 is used in this research work. Grade of bitumen used in the pavements should be selected on the basis of climatic conditions and their performance in past. It fills the voids, cause particle adhesion and offers impermeability.

3.1.5 Polyethylene

Stabilizing additives are used in the mixture to provide better binding property. Now-a days polypropylene, polyester, mineral and cellulose are commonly used as fibers. In this present study polyethylene is used as stabilizing additive to improve performance characteristics of pavement.

3.2 Materials used in present study

3.2.1 Aggregates

For preparation of Bituminous mixes (SMA, DBM, BC) aggregates as per MORTH grading as given in Table 3.1, Table 3.2 and Table 3.3 respectively, a particular type of binder and polyethylene in required quantities were mixes as per Marshall procedure. The specific gravity and physical properties of aggregate are given in Table-3.4 and Table-3.5.

Table 3.1: Gradation of aggregates for SMA

Sieve size (mm)	Percentage passing
19	100
13.2	94
9.5	62
4.75	28
2.36	24
1.18	21
0.6	18
0.3	16
0.075	10

Table 3.2: Gradation of aggregates for BC

Sieve size (mm)	Percentage passing
19	100
13.2	79-100
9.5	70-88
4.75	53-71
2.36	42-58
1.18	34-48
0.6	26-38
0.3	18-28
0.15	12-20
0.075	4-10

Table 3.3: Gradation of aggregates for DBM

Sieve size (mm)	Percentage passing
37.5	100
26.5	90-100
19	71-95
13.2	56-80
9.5	-
4.75	38-54
2.36	28-42
1.18	-
0.6	-
0.3	7-21
0.15	-
0.075	2-8

Table 3.4: Specific gravity of aggregates

Types of aggregates	Specific gravity
Coarse	2.75
Fine (Stone)	2.6
Fine(Slag)	2.45
Filler(Stone dust)	2.7
Filler(Fly ash)	2.3

Table 3.5: Physical properties of coarse aggregates

Property	Test Method	Test Result
Aggregate Impact Value (%)	IS: 2386 (P IV)	14.3
Aggregate Crushing Value (%)	IS: 2386 (P IV)	13.02
Los Angels Abrasion Value (%)	IS: 2386 (P IV)	18
Flakiness Index (%)	IS: 2386 (P I)	18.83
Elongation Index (%)	IS: 2386 (P I)	21.5
Water Absorption (%)	IS: 2386 (P III)	0.1

3.2.2 Fly ash& Slag

Both the fly ash and slag used in present investigation are collected from Rourkela steel plant. The chemical composition and XRD results are given in Table 3.6.

Table 3.6: Chemical composition of fly ash and slag in percentage (by weight)

Constituents	Fly ash	Slag
Fe_2O_3	10.3%	4.012%
CaO	4.206%	26.638%
MgO	3.023%	16.124%
Sillica	56.4%	32.14%
Al_2O_3	29%	21%
Carbon	7.18%	0%

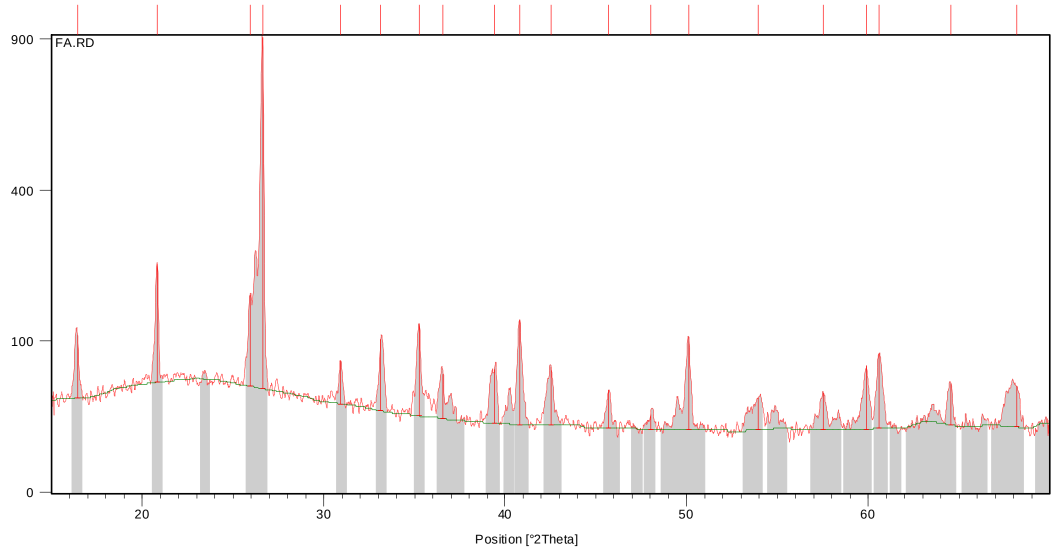


Fig. 3.1 XRD result of fly ash

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	83-0539	77	Quartz	0.000	0.983	SiO_2
*	79-1454	67	Mullite - synthetic	0.000	0.197	Al 4.75 Si1.25 O9.63

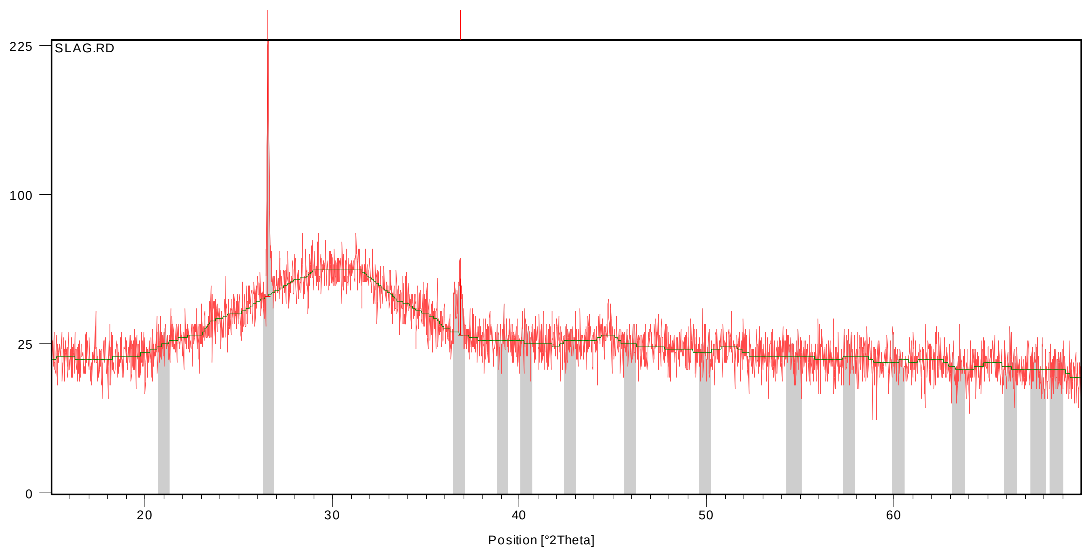


Fig. 3.2 XRD result of granulated blast furnace slag

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	81-0065	42	Silicon Oxide	0.000	0.931	Si O_2

3.2.3 Binder

One conventional commonly used bituminous binder, namely VG 30 bitumen was used in this investigation to prepare the samples. Conventional tests were performed to determine the physical properties of these binders. The physical properties thus obtained are summarized in Table 3.7.

Table 3.7: Physical properties of binder

Property	Test Method	Value
Penetration at 25 ℃ (mm)	IS : 1203-1978	67.7
Softening Point (℃)	IS : 1203-1978	48.5
Specific gravity	IS : 1203-1978	1.03

3.2.3 Polyethylene

In present study polyethylene is used as stabilizing additive (OMFED polyethylene used for milk packaging which is locally available). The Omfed polyethylene packets were collected; they were washed and cleaned by putting them in hot water for 3-4 hours. They were then dried.

Shredding

The dried polyethylene packets were cut into thin pieces of size 50 mm×5 mm maximum. This is because to maintain uniformity in size of polyethylene in mix. When the polyethylene is to be added with bitumen and aggregate it is to be ensured that the mixing will be proper.

Specific Gravity of polythene was found as 0.905.

Fig. 3.3: OMFED polyethylene used

Table 3.7: Physical properties of polyethylene used

Properties	Results
Specific gravity	0.905
Softening point	54.22℃
Young modulus	109.75 Mpa
Strain at break	1351 %
Strain at peak	1271.5 %
Displacement at break	135.15 mm
Displacement at peak	127.15 mm
Load at peak	.0146 kn
Stress at peak	14.59 Mpa

CHAPTER 4

EXPERIMENTAL WORK

4.1 General

This chapter describes the experimental works carried out in this present investigation. It involves mainly 2 processes. i.e.

- Preparation of Marshall samples
- Tests on samples

Prior to the experimental work, the specific gravity, tensile strength, and softening point of polythene used in this investigation were calculated.

4.1.1 Determination of specific gravity of polyethylene

Specific gravity of polyethylene was found out by following the guidelines of ASTM D792-08. The procedure adopted is given below;

- The weight of the polyethylene in air was measured by a balance. Let it be denoted by "a".
- An immersion vessel full of water was kept below the balance.
- A piece of iron wire was attached to the balance such that it is suspended about 25 mm above the vessel support.
- The polyethylene was then tied with a sink by the iron wire and allowed to submerge in the vessel and the weight was measured. Let it be denoted as "b".
- Then polyethylene was removed and the weight of the wire and the sink was measured by submerging them inside water. Let it be denoted as "w".

The specific gravity is given by

s = a / (a + w - b)

Where:

a = Apparent mass of specimen, without wire or sinker, in air

b = Apparent mass of specimen and of sinker completely immersed and of the wire partially immersed in liquid

w = Apparent mass of totally immersed sinker and of partially immersed wire.

From the experiment, it was found that

a = 19 gm

b = 24 gm

w = 26 gm

=> s = 19 / (19+26-24) = 19/21 =0.90476

Take specific gravity of polyethylene = 0.905.

4.1.2 Determination of tensile properties of polyethylene

The ability to resist breaking under tensile stress is one of the most important and widely measured properties of materials. Tensile strength of polyethylene was calculated by using INSTORN – 1195 CORPORATION with Sample rate = 9.103 pts/sec and Crosshead speed (speed at which sample is stretched) = 50 mm/min. Rectangular Polyethylene samples were prepared according to ASTM D882. Dimension of polyethylene was measured by using digital Vernier calliper (Width = 10mm, Thickness = 0.1mm, Gauge length = 10mm, Grip distance = 40mm). The following results are found out from this test;

Young's modulus (also called as tensile modulus) = $\frac{\text{Stress}}{\text{Elastic strain}} =$ 109.75 Mpa

Strain at break = 1351 %

Strain at peak = 1271.5 %

Displacement at break = 135.15 mm

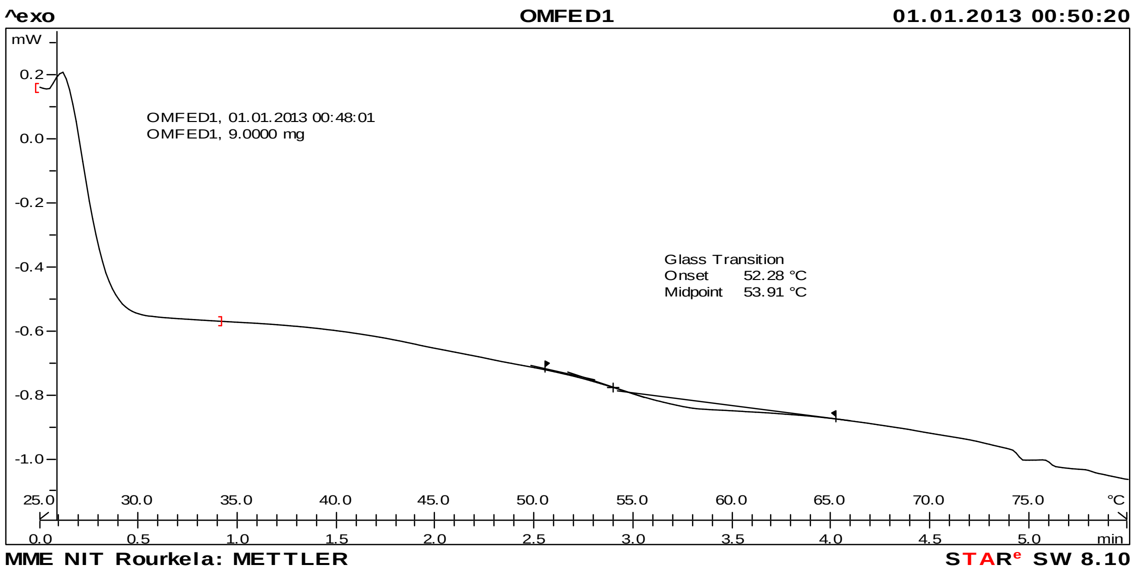
Displacement at peak = 127.15 mm

Load at peak = .0146 kn

Stress at peak =14.59 Mpa (Stress at peak or ultimate tensile strength or tensile strength at break is the percentage increase in length that occurs under tension before break. If polyethylene possesses high elongation and high ultimate tensile strength it is called as tough)

4.1.3 Determination of softening point of polyethylene

Softening point of polyethylene was determined by using DSC 822, a low temperature differential scanning calorimeter with rate of heating 10℃ $/min$. The temperature was maintained in between 25 ℃- 80℃ according to melting point of polyethylene. The glass transition temperature is found as 54.22℃ (It the temperature at which phase change occurs and it is the service temperature).



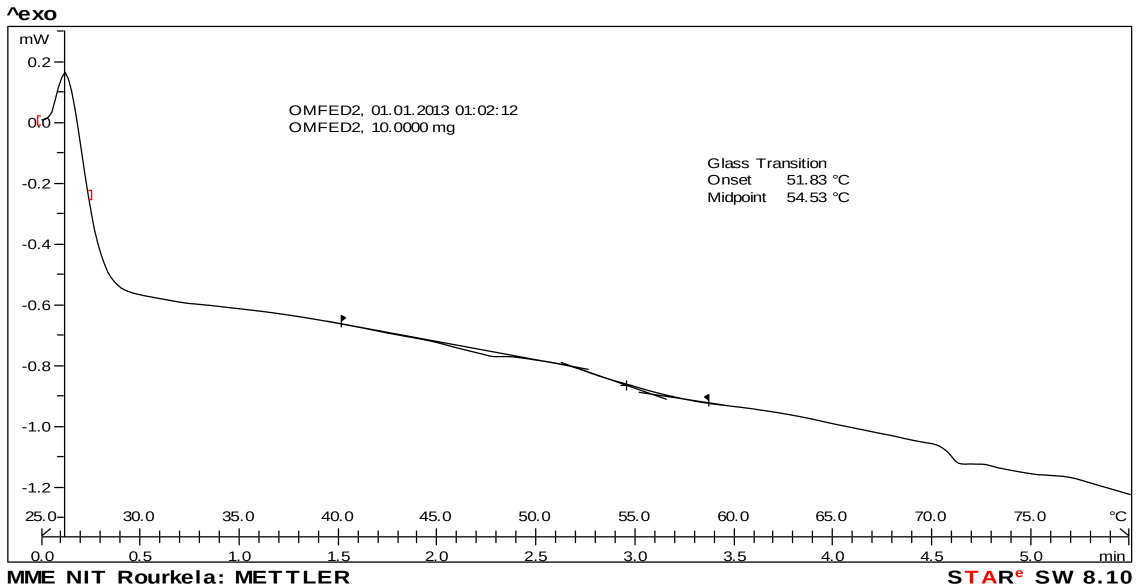


Fig 4.1 Results of two set of polyethylene samples given by DSC 822

4.2 Preparation of Marshall samples

The mixes were prepared according to the Marshall procedure specified in ASTM D1559. For SMA, BC, and DBM mixes the coarse aggregates, fine aggregates and filler were mixed with bitumen and polyethylene according to the adopted gradation as given in Table 3.1, Table 3.2, and Table 3.3 respectively. First a comparative study was done on SMA, BC, and DBM mixes by using stone dust as filler in between with and without polyethylene in mixes. Again a comparative study was done on SMA, BC, and DBM mixes by using slag and fly ash as filler in between with and without polyethylene in mixes. Here Optimum Binder Content (OBC) and optimum polyethylene content (OPC) was found by Marshall Test. The mixing of ingredients was done as per the following procedure;

- Required quantities of coarse aggregate, fine aggregate & mineral fillers were taken in an iron pan and kept in an oven at temperature 160˚C for 2 hours. Preheating is required because the aggregates and bitumen are to be mixed in heated state.
- The required amount of shredded polythene was weighed and kept in a separate container.

- The aggregates in the pan were heated on a controlled gas stove for a few minutes maintaining the above temperature. Then the polyethylene was added to the aggregate and was mixed for 2 minutes.
- Now bitumen was added to this mix and the whole mix was stirred uniformly and homogenously. This was continued for 15-20 minutes till they were properly mixed which was evident from the uniform colour throughout the mix.
- Then the mix was transferred to a casting mould. 75 no. of blows were given per each side of the sample so subtotal of 150 no. of blows was given per sample. Then each sample was marked and kept separately.

4.3 Tests on Marshall samples

4.3.1 Marshall test

In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm/min. Here are two major features of the Marshall method of mix design.

(i) Stability, flow tests and

(ii) Voids analysis.

The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load. In India, it is a very popular method of characterization of bituminous mixes due to its simplicity and low cost. In the present study the Marshall properties such as stability, flow value, unit weight and air voids were studied to obtain the optimum binder contents (OBC) and optimum polyethylene contents (OPC).

Fig. 4.2 Marshall test in progress

4.3.1.1 Retained stability test

Retained Stability is the measure of moisture induced striping in the mix and subsequent loss of stability due to weakened bond between aggregates and binder. The test was conducted following STP 204-22 on the Marshall machine with the normal Marshall samples. The stability was determined after placing the samples in water bath at 60 °C for half an hour and 24 hours.

Retained stability $= \frac{s_2 \times 100}{s_1}$

S_2 =Soaked stability (after soaking of 24 hours at 60°C)

S_1= Standard stability

4.3.2 Drain down test

This test method covers the determination of the amount of drain down in un-compacted asphalt mixture sample when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport, and placement of the mixture. The test is particularly applicable to mixtures such as open-graded friction course and Stone Matrix Asphalt (SMA). The drain down method suggested by MORTH (2001) was adopted in this study. The drainage baskets fabricated locally is shown in Fig-4.2. The loose un-compacted mixes were transferred to the drainage baskets and kept in a pre-heated oven maintained at 150°C for three hours. Pre-weighed plates were kept below the drainage baskets when placed inside oven to collect the drained out binder drippings. From the drain down test the binder drainage has been calculated from the equation:-

Drain down equation is = $\frac{W_2 - W_1}{X} \times 100$

Where,

W_1= Initial mass of the plate

W_2= Final mass of the plate and drained binder

X = Initial mass of the mix

For a particular binder three mixes were prepared at its optimum binder content and the drain down was reported as an average of the three.

Fig. 4.3 Drain down test of SMA without polyethylene

4.3.3 Static indirect tensile strength test

In this test, a compressive load of 51 mm/minute is applied on a cylindrical Marshall specimen along a vertical diametrical plane through two curved strips made up of stainless steel, whose radius of curvature is same as that of the specimen. The sample was kept in the Perspex water bath maintained at the required temperature for minimum 1/2 hours before test, and the same temperature was maintained during test. This loading configuration developed a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametric plane and the specimen failed by splitting along the vertical diameter.

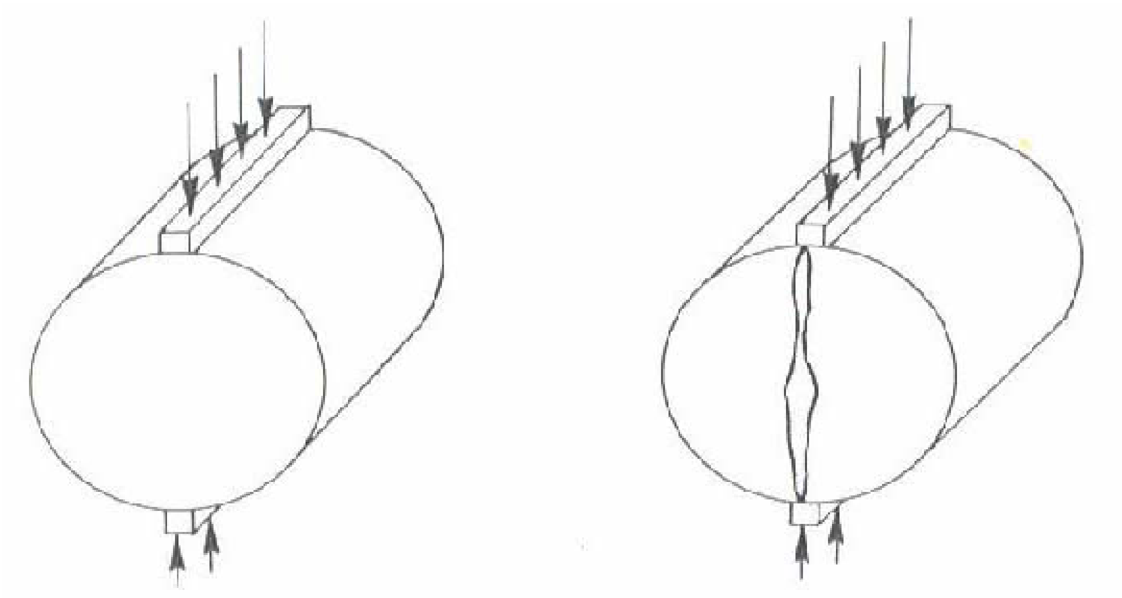


Fig. 4.4 Loading configuration for indirect tensile strength test

The tensile strength of the specimen was calculated according to ASTM D 6931 (2007) from the failure load noted from the dial gauge of the proving ring.

$$S_T = \frac{2 \times P}{\Pi \times D \times T}$$

Where

S_T = Indirect Tensile Strength, KPa

P = Maximum Load, KN

T = Specimen height before testing, mm

D = Specimen Diameter, mm

The test temperature was varied from 5℃ to 40℃ at an increment of 5℃. The tensile strength was reported as the average of the three test results.

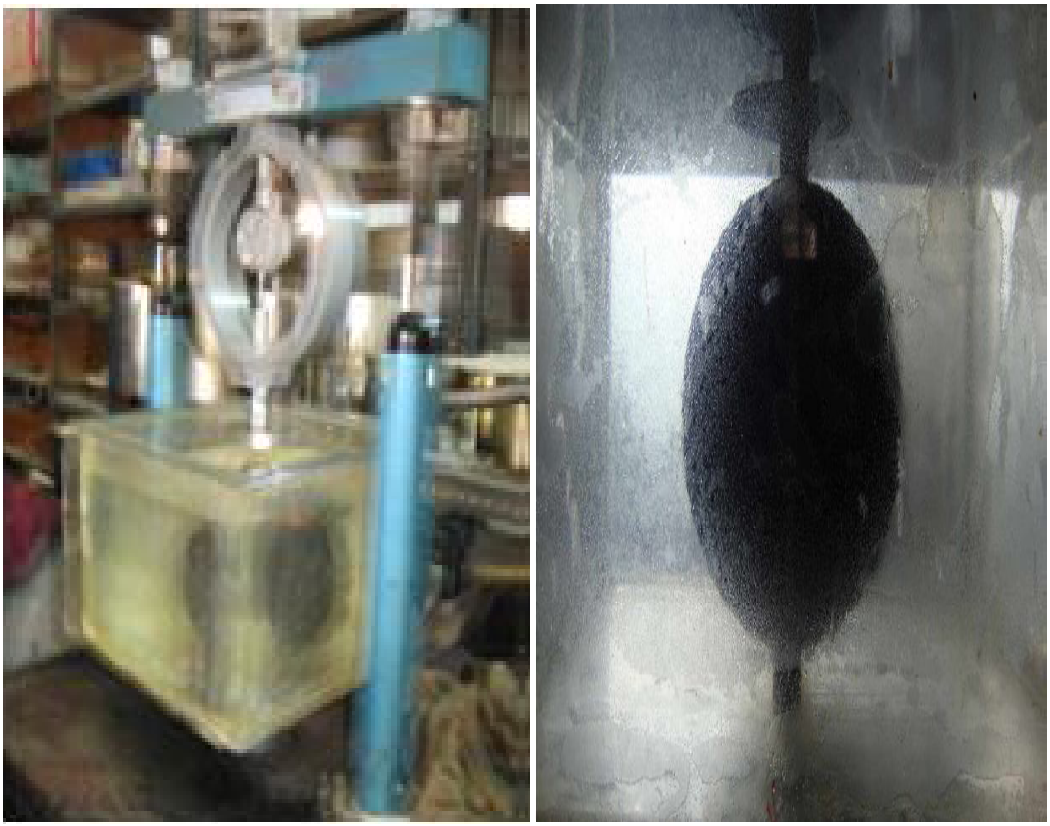


Fig. 4.5 Close view of indirect tensile strength test on progress

4.3.3.1 Tensile strength ratio

The tensile strength ratio of asphalt mixes is an indicator of their resistance to moisture susceptibility. The test was carried out by loading a Marshall specimen with compressive load acting along the vertical diametric-loading plane. The test was conducted followed by AASHTO T 283 at 25°C temperature and the tensile strength calculated from the load at which the specimen fails is taken as the dry tensile strength of the asphalt mix. The specimens were then placed in a water bath maintained at 60°C for 24 hours and then immediately placed in an environmental chamber maintained at 25°C for two hours. These conditioned specimens were then tested for their tensile strength. The ratio of the indirect tensile strength (ITS) of the water-conditioned specimens to that of dry specimens is the tensile strength ratio.

$$\text{Tensile strength ratio (TSR)} = \frac{\text{ITS of conditioned specimen set}}{\text{ITS of unconditional specimen set}} \times 100$$

4.3.4 Static creep test

This test method is used to determine the resistance to permanent deformation of bituminous mixtures at specific temperatures. For Static Creep test sample were prepared at their optimum binder content (OBC) and optimum polyethylene content (OPC) and the test was conducted following Texas department of transportation (2005). The specimens were placed in a controlled temperature chamber maintained at specific temperatures (30˚C, 40°C, 50˚C, 60℃) for three to five hours prior to start of the test. Then three cycles of a 125 lb. (556 N) load was applied for one-minute intervals followed by a one-minute rest period for each cycle. This allows the loading platens to achieve more uniform contact with the specimen. The test consists of two stages. In first stage a vertical load of 556 N is applied for 1hours. The deformation was registered in each 5 min intervals starting from 0 min to 60 min by using a dial gauge graduated in units of 0.002 mm. Secondly, the load was removed and its deformation was registered up to next 5 min at 1 min intervals. This test was carried out at different temperature such as 30℃, 40℃, 50℃, 60℃. A graph has been plot between time-deformation. Then the deformation was converted to the following relationship.

$$\text{Strain} = \frac{\text{Deformation}}{\text{Specimen thickness}}$$

CHAPTER 5

ANALYSIS OF RESULTS AND DISCUSSION

5.1 Introductions

This chapter deals with test results and analysis carried out in previous chapter. This chapter is divided into four sections. First section is deals with parameter used for analysis of different test results. Second section deals with calculation and comparison of optimum binder content (OBC) and optimum polyethylene content (OPC) of SMA, BC, and DBM mixes with and without polyethylene with stone dust used as filler. Third section deals with calculation and comparison of Optimum binder Content (OBC) and Optimum polyethylene content (OPC) of SMA, BC, and DBM mixes with or without polyethylene by replacing some gradation of fine aggregate by granulated blast furnace slag with fly ash as filler. Fourth section deals with analysis of test results of drain down test, static indirect tensile and static creep test at different test temperature.

5.2 Parameters used

All the Marshall properties were calculated as per Das A. and Chakraborty P. (2010) and the definitions and other formulae used in calculations are explained below.

Bulk specific gravity of aggregate (G_{Sb})

$$Gsb = \frac{M_{agg}}{\text{Volume of(mass of agg.+air void in agg.+absorved bitumen)}}$$

Where Magg = Mass of aggregate

Effective specific gravity of aggregate (G_{se})

$$Gse = \frac{M_{agg}}{\text{Volume of(mass of agg+air void in agg)}}$$

Where Magg = mass of aggregate

$$Gse = (M_{mix} - M_b) / \left(\frac{M_{Mix}}{G_{mm}} - \frac{M_b}{G_b}\right)$$

Where M_b = mass of bitumen used in mix

G_b= specific gravity of bitumen

Apparent specific gravity (G_a)

$$G_a = \frac{M_{agg}}{\text{Volume of aggmass}}$$

Theoretical maximum specific gravity of mix (G_{mm})

$$G_{mm} = \frac{M_{mix}}{\text{Volume of (mix – air void)}}$$

Bulk specific gravity of mix (G_{mb})

$$G_{mb} = \frac{M_{mix}}{\text{Bulk volume of mix}}$$

Air voids (VA):-

$$VA = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100$$

Voids in mineral aggregates (VMA)

$$VMA = \left[1 - \frac{G_{mb}}{G_{mm}} \times P_S\right] \times 100$$

Where P_S= percentage of aggregate present by total mass of mix

Voids filled with bitumen (VFB)

$$VFB = \frac{VMA - VA}{VMA} \times 100$$

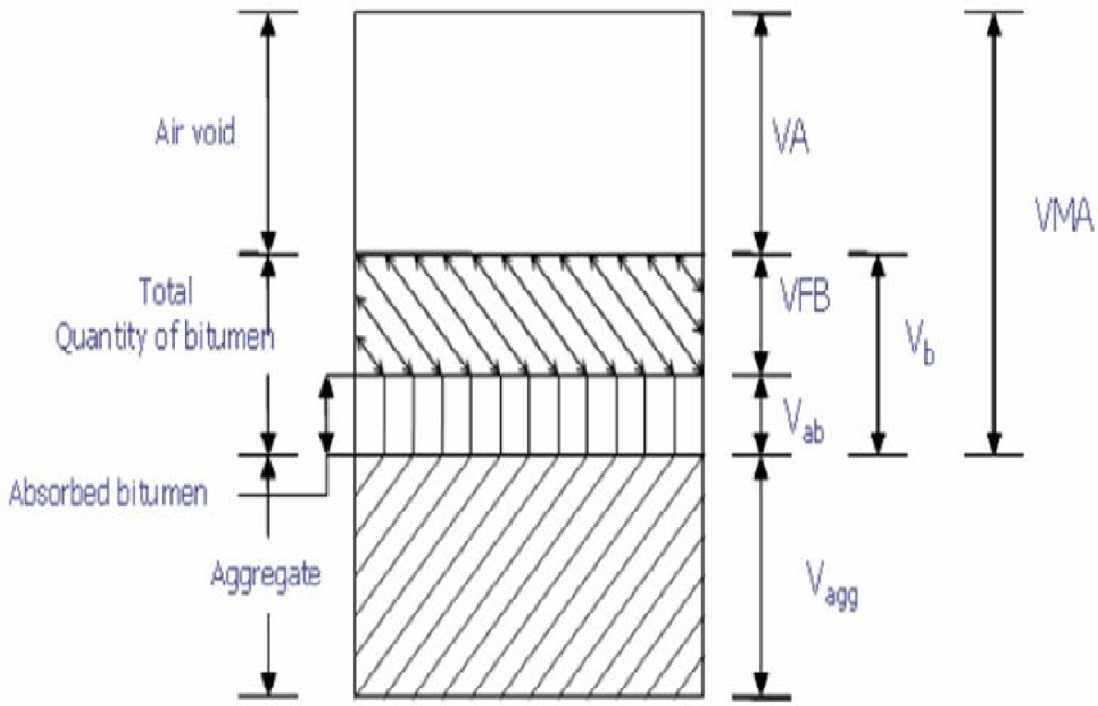


Fig.-5.1 Phase diagram of bituminous mix

5.3 Effect of polyethylene concentration on Marshall properties of SMA, BC and DBM mixes with stone dust as filler

Here result in variation of Marshall properties with different binder content where polyethylene content is taken as 0%, 0.5%, 1%, 1.5%, 2% and 2.5% for SMA and DBM and 0%, 0.5%, 1%, 1.5%, 2% for BC are explained below.

5.3.1 Marshall stability

It is observed from graphs that with increase in bitumen concentration the Marshall stability value increases up to certain bitumen content and there after it decreases. That particular bitumen content is called as optimum binder content (OBC). In present study OBC for conventional SMA, BC, and DBM mixes are found as 6%, 4.5%, and 4.5% and similarly

OBC are found as 4% for modified SMA, BC and DBM mixes with polyethylene at different concentration. From the graphs it can be observed that with addition of polyethylene stability value also increases up to certain limits and further addition decreases the stability. This may be due to excess amount of polyethylene which is not able to mix in asphalt properly. That polyethylene concentration in mix is called optimum polyethylene content (OPC) which is found as 2% for SMA and DBM and 1.5% for BC mixes.

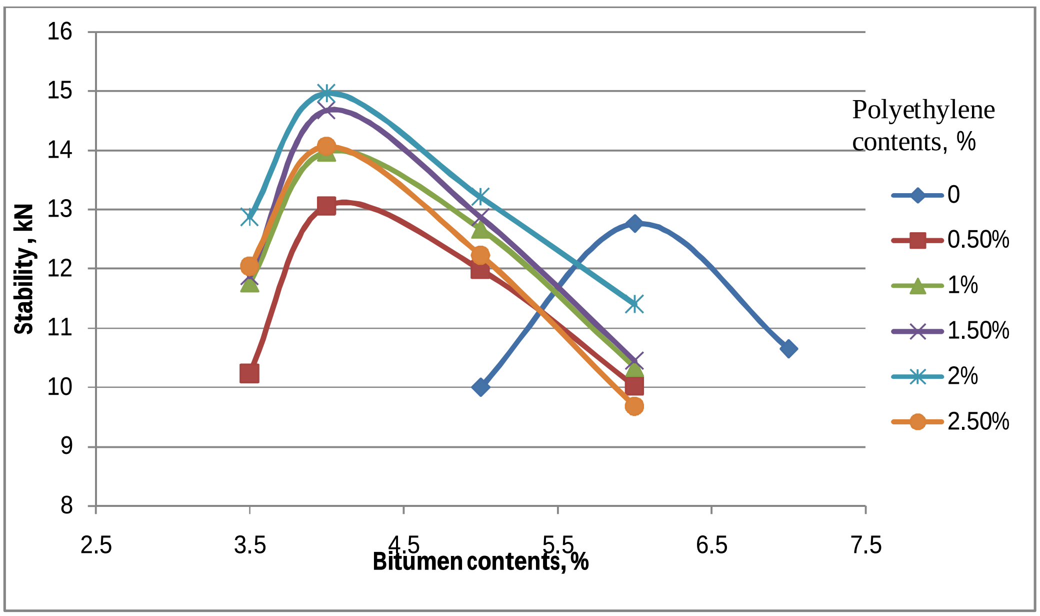


Fig 5.2 Variations of Marshall Stabilities of SMA with different binder and polyethylene contents

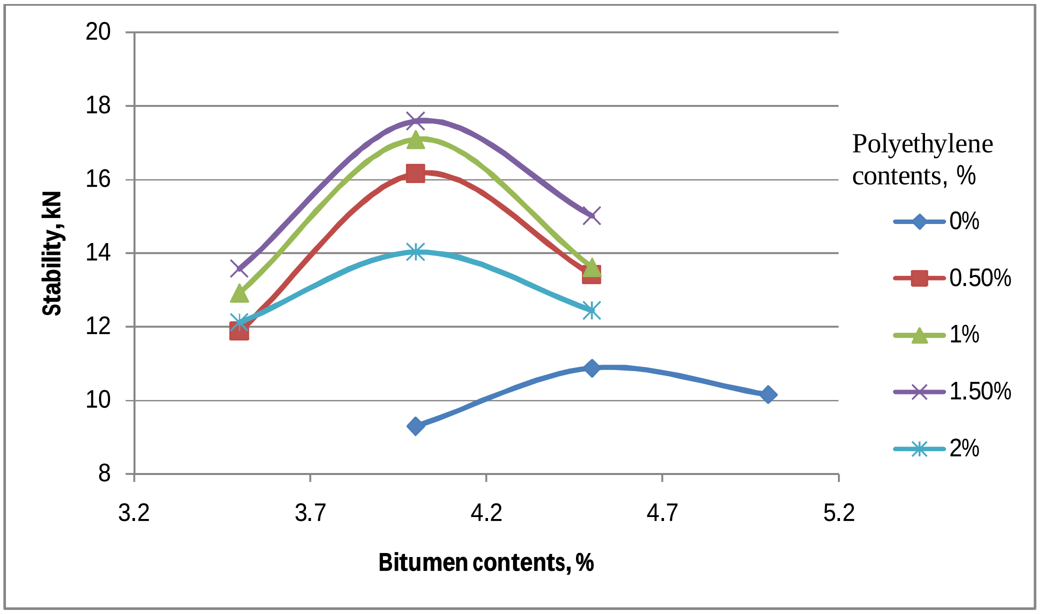


Fig. 5.3 Variations of Marshall Stabilities of BC with different binder and polyethylene contents

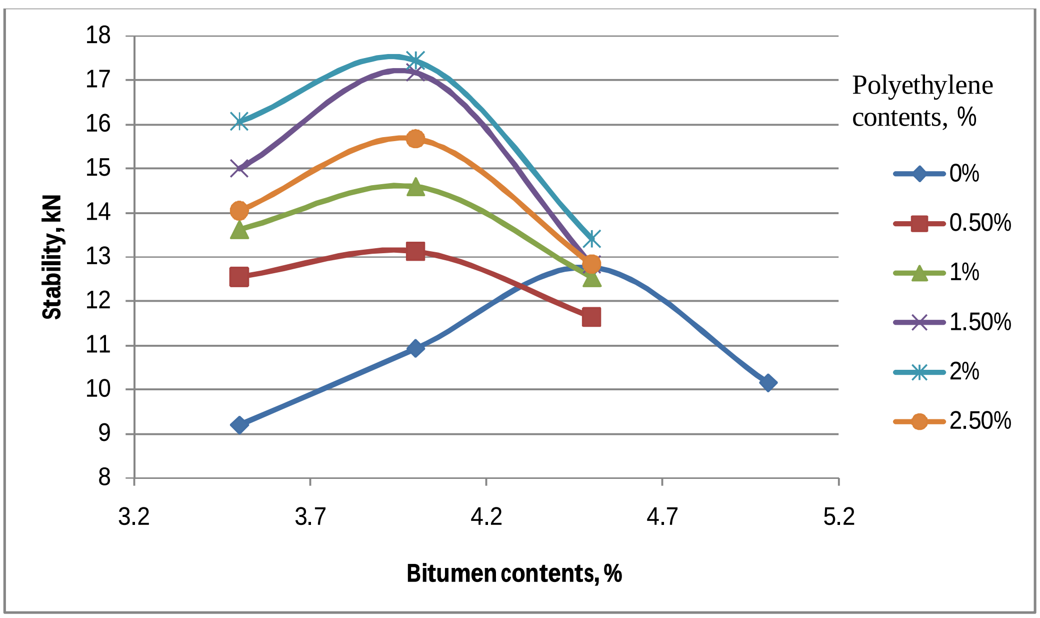


Fig. 5.4 variations of Marshall Stabilities of DBM with different binder and polyethylene contents

5.3.2 Flow value

It is observed from graphs that with increase in binder content flow value increases but by addition of polyethylene flow value decreases than that of conventional mixes, again further addition of polyethylene after OPC the flow value stars to increase.

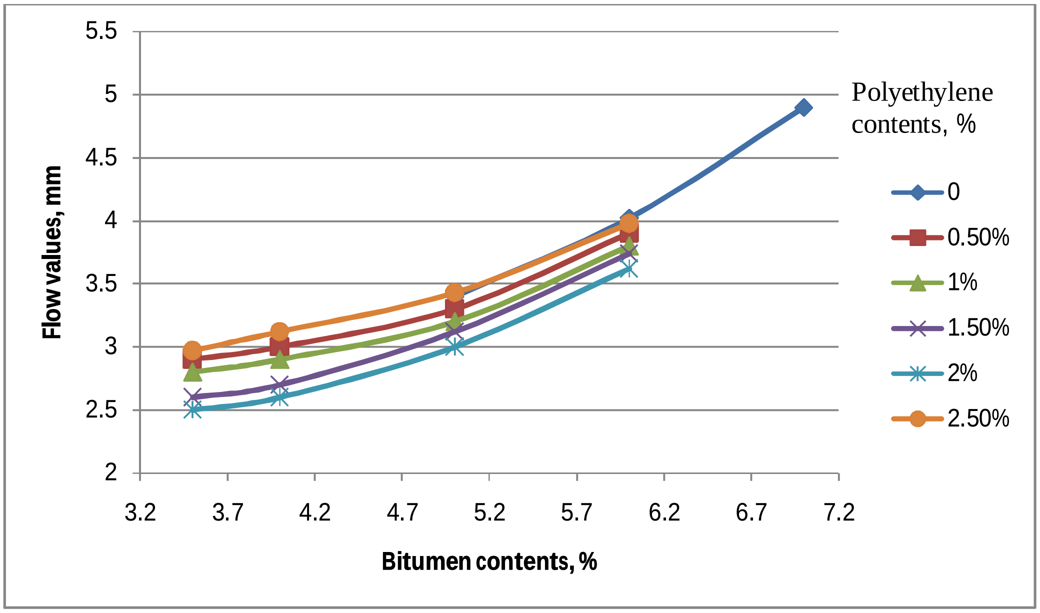


Fig. 5.5 Variations of flows value of SMA with different binder and polyethylene contents

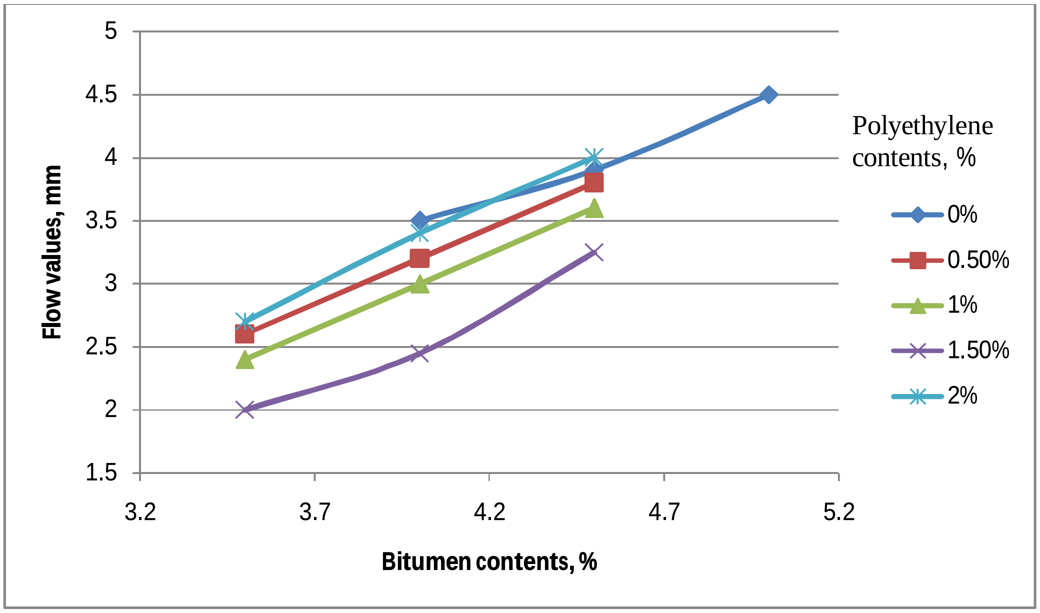


Fig. 5.6 Variations of flow values of BC with different binder and polyethylene contents

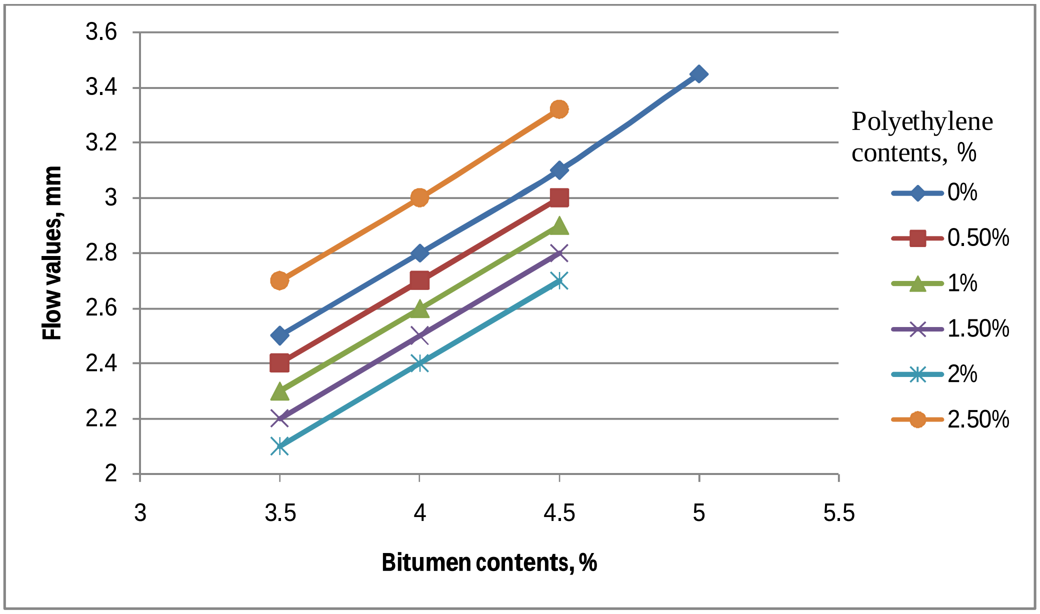


Fig. 5.7 Variations of flow values of DMB with different binder and polyethylene contents

5.3.3 Unit weight

It is observed that unit weight is increasing with increase binder concentration up to certain binder content i.e, OBC; then decreasing. With increase in polyethylene concentration in mixes its value decreases than conventional mix. It happens may be due to lighter weight of polyethylene as compared to bitumen.

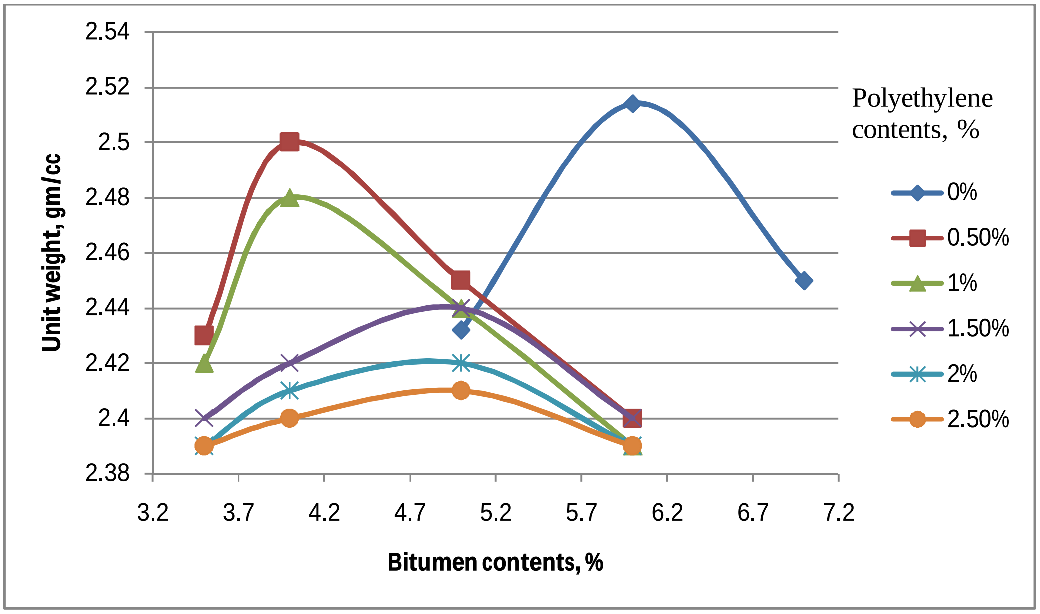


Fig. 5.8 Variations of unit weight values of SMA with different binder and polyethylene contents

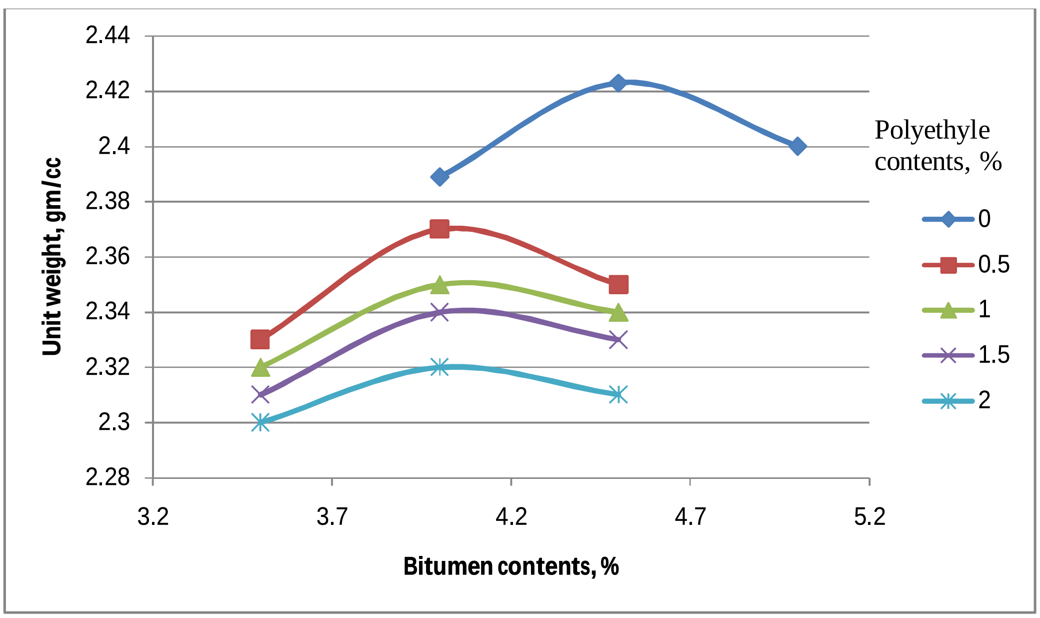


Fig. 5.9 Variations of unit weight values of BC with different binder and polyethylene contents

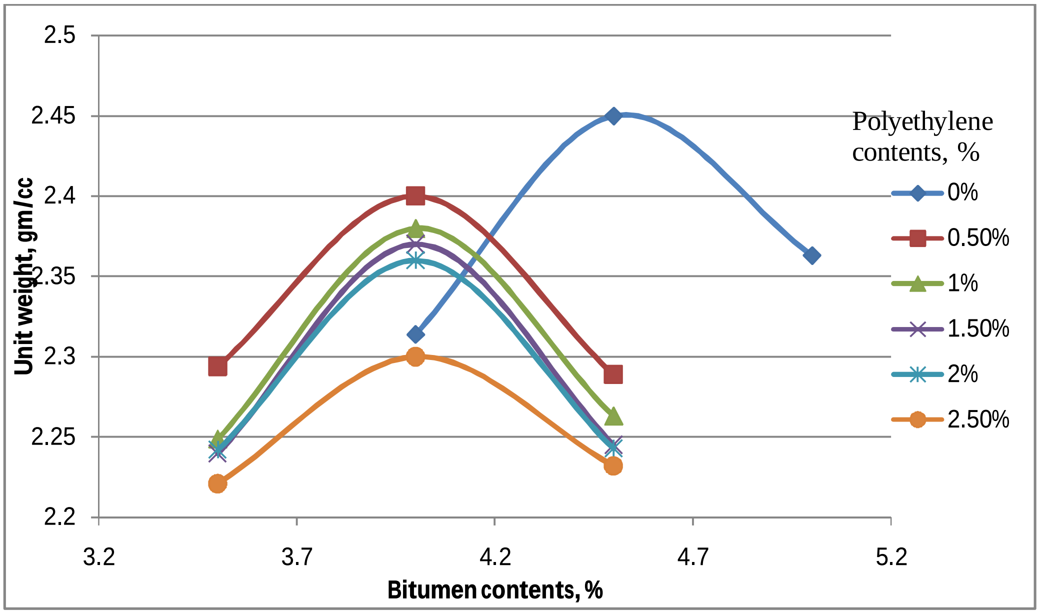


Fig. 5.10 variations of unit weight values of DBM with different binder and polyethylene contents

5.3.4 Air void (VA)

It is observed that with increase in binder content air void decreases. But with addition of polyethylene to mix the air void is increasing than that of conventional mixes.

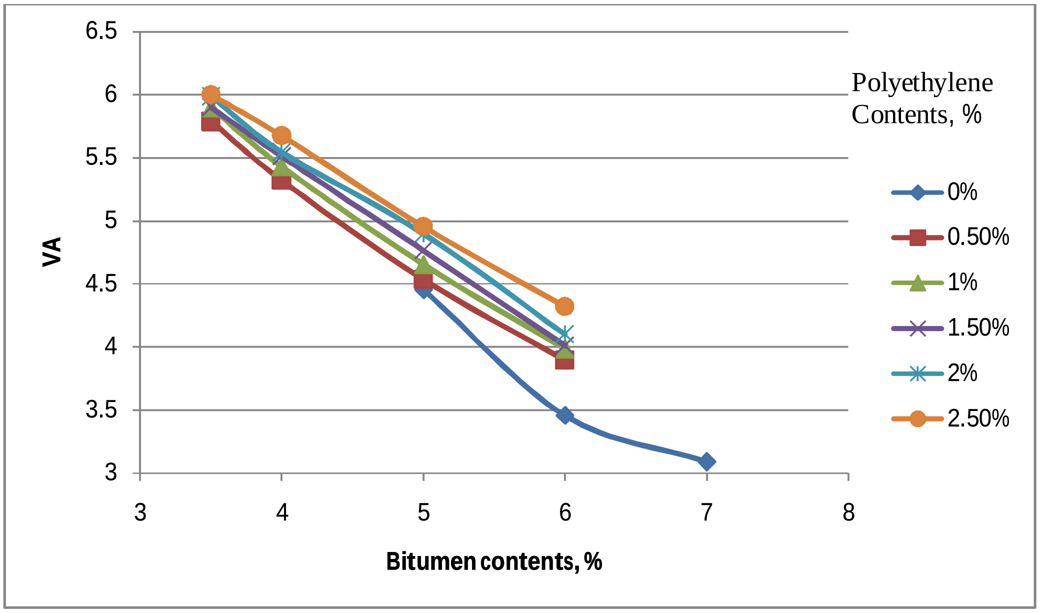


Fig. 5.11 Variations of VA values of SMA with different binder and polyethylene contents

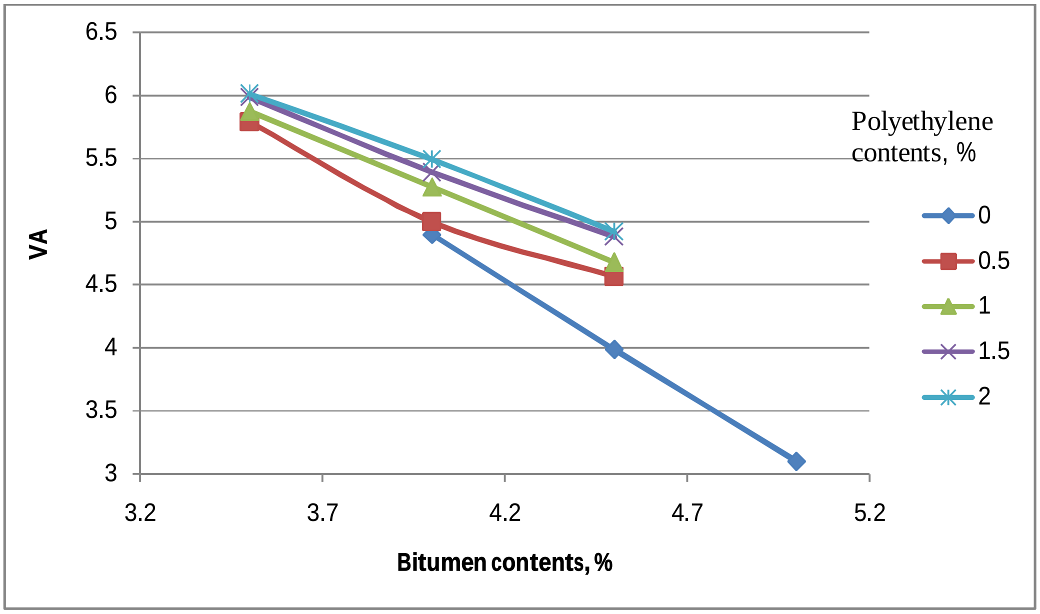


Fig. 5.12 Variations of VA values of BC with different binder and polyethylene contents

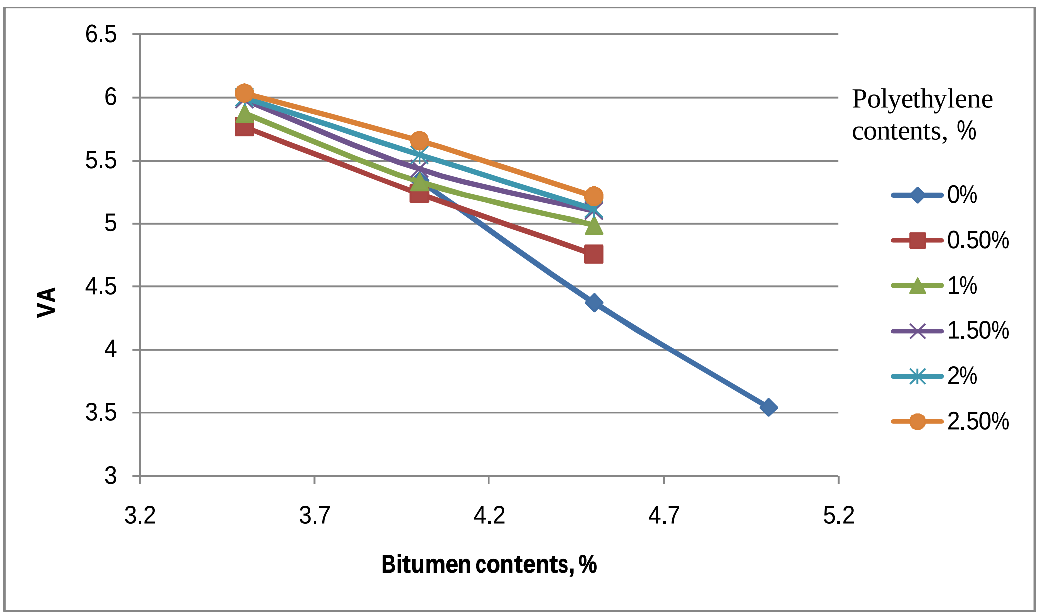


Fig. 5.13 Variations of VA values of DBM with different binder and polyethylene contents

5.3.5 Void in mineral aggregate (VMA)

It is observed that first VMA decreases and then it increases at sharp rate with increase in bitumen concentration in mixes. Variation of VMA values with different binder contents and with different polyethylene contents are shown in graphs below. From the graphs it is observed that with addition of polyethylene to mix the VMA values increases than that of conventional mixes.

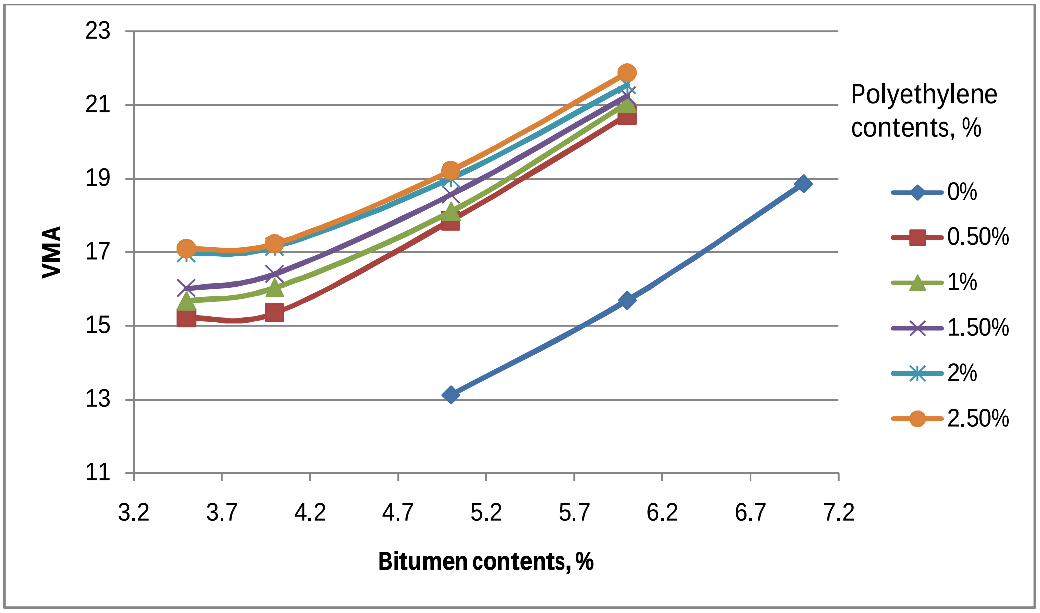


Fig. 5.14 Variations of VMA values of SMA with different binder and polyethylene content

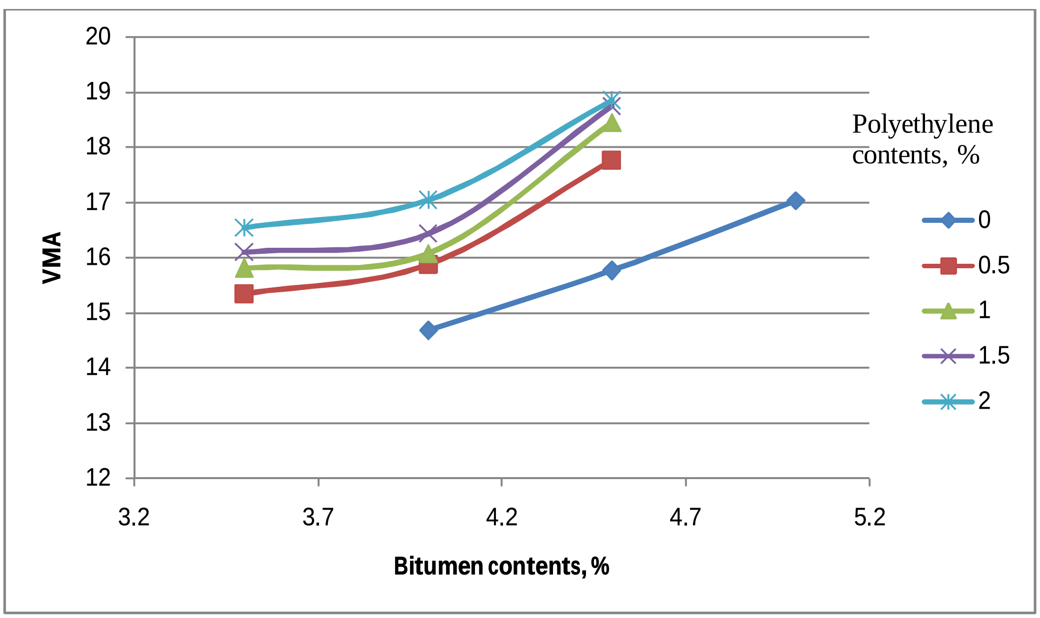


Fig. 5.15 Variations of VMA values of BC with different binder and polyethylene content

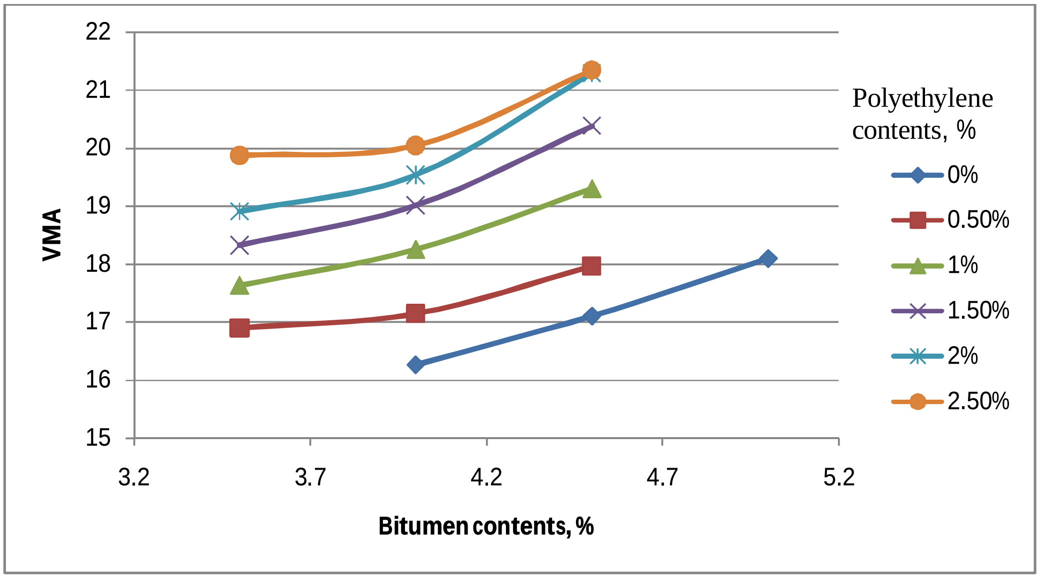


Fig. 5.16 Variations of VMA values of DBM with different binder and polyethylene content

5.3.6 Void filled with bitumen (VFB)

It is observed that VFB values of different mixes increase at sharp rate with increase in bitumen concentration. Variation of VFB with different binder content with different polyethylene content is shown in graphs below. From these graphs it is observed that with addition of polyethylene to mix the VFB increases than that of conventional mixes.

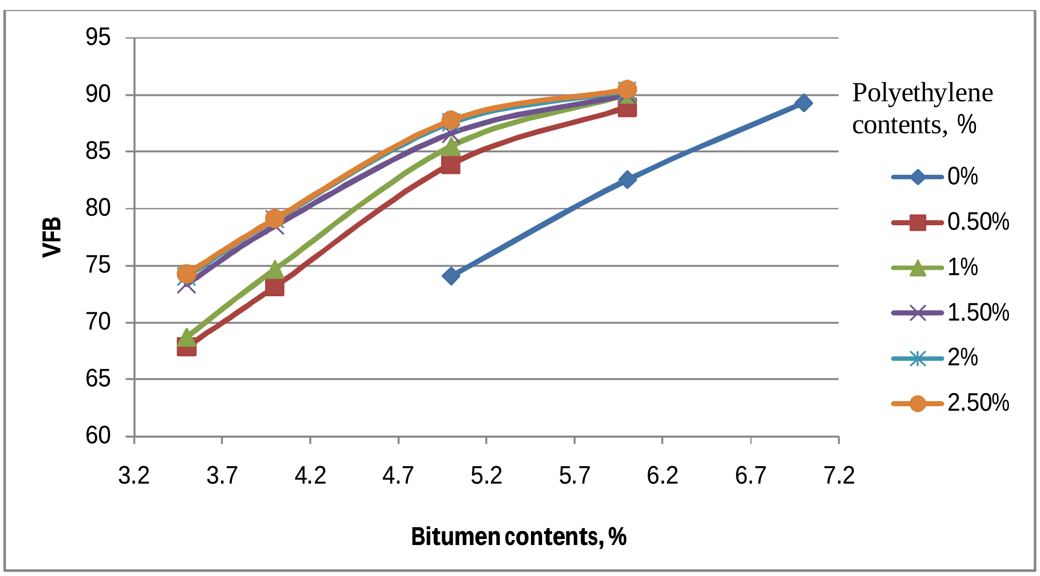


Fig. 5.17 Variations of VFB values of SMA with different binder and polyethylene content

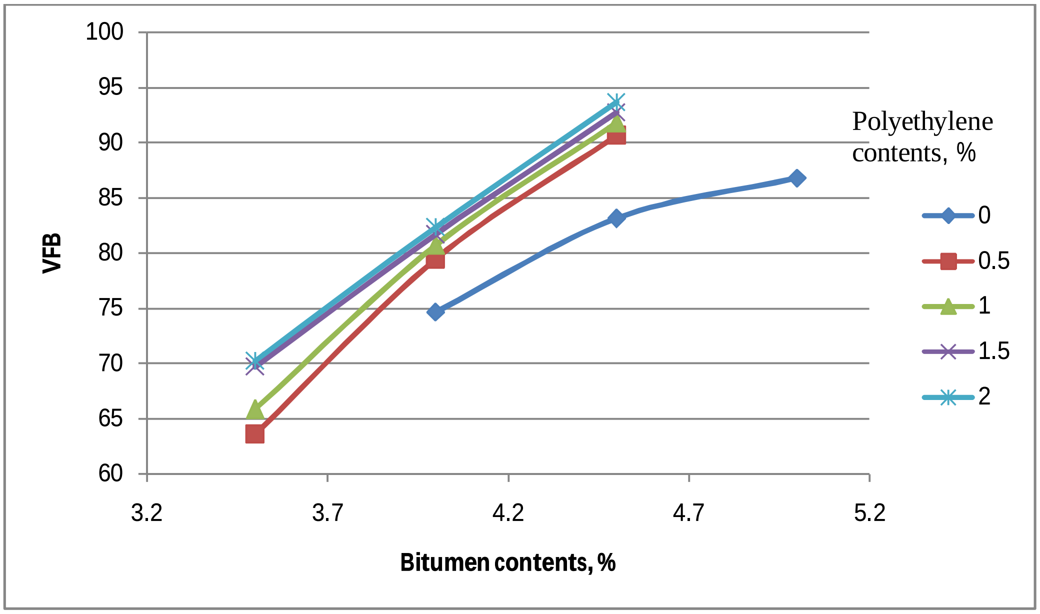


Fig. 5.18 Variations of VFB values of BC with different binder and polyethylene content

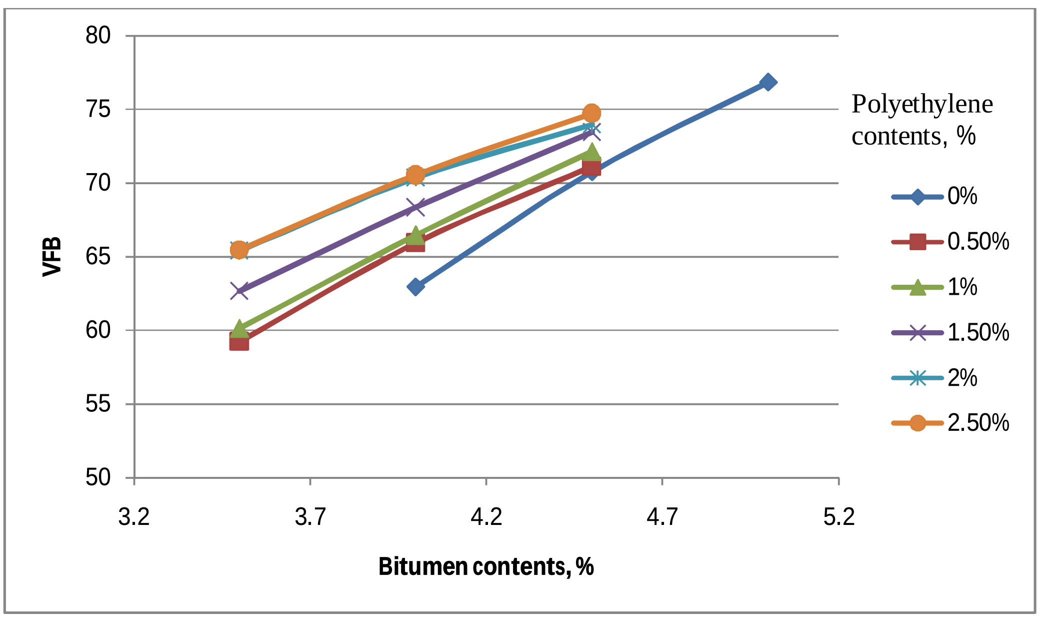


Fig. 5.19 Variations of VFB values of DBM with different binder and polyethylene content

Table 5.1 Optimum binder contents

Types of mix	Optimum polyethylene content (%)	Optimum binder content (%)
SMA without polyethylene	0%	6%
SMA with polyethylene	2%	4%
DBM without polyethylene	0%	4.5%
DBM with polyethylene	2%	4%
BC without polyethylene	0%	4.5%
BC with polyethylene	1.5%	4%

Table 5.2 comparisons of stabilities at OBC

Types of mix with stone dust	Stability(kN)
SMA without polyethylene	12.765
SMA with polyethylene	14.965
DBM without polyethylene	12.76
DBM with polyethylene	17.444
BC without polyethylene	10.875
BC with polyethylene	17.587

Table 5.3 Comparisons of flow values at OBC

Types of mix with stone dust	Flow(mm)
SMA without polyethylene	3.9
SMA with polyethylene	3
DBM without polyethylene	4.02
DBM with polyethylene	2.6
BC without polyethylene	3.9
BC with polyethylene	2.45

5.3.7 Retained stability

Retained stability is calculated for SMA, BC, and DBM mixes for both of with polyethylene and without polyethylene. It is observed that the addition of polyethylene to the mixture the retained stability value increases. It is analyzed that the BC with polyethylene results in highest retained stability followed by DBM with polyethylene and then SMA with polyethylene.

Table 5.4 Retained stability of SMA, BC, and DBM with and without polyethylene

Types of mix	Avg. stability after half an hour in water at 60 °c	Avg. stability after 24 hours in water at 60 °c	Avg. retained Stability, in %	Design requirement
SMA without polyethylene	10.932	8.497	73.22	Minimum 75% (as per MORTH Table 500-17)
SMA with polyethylene	10.875	8.497	78.13	
DBM without polyethylene	12.765	9.962	74.04	
DBM with polyethylene	14.965	12.013	80.27	
BC without polyethylene	17.587	14.13725	76.38	
BC with polyethylene	17.444	14.2105	81.46	

5.4 Effect of polyethylene concentration on Marshall properties of SMA, BC and DBM mixes with slag as a part of fine aggregates and fly ash as filler

Here the test result in variation of Marshall properties with different binder content where polyethylene content is taken as 0%, 0.5%, 1%, 1.5%, and 2% for SMA , BC, and DBM mixes are explained below by replacing two gradation (0.3mm-0.15mm and 0.15mm - 0.075mm) of fine aggregates by granulated blast furnace slag and using fly ash as filler.

5.4.1 Marshall stability

It is observed from graphs that after replacement of fine aggregate by slag and filler by fly ash OBC for SMA, BC, and DBM mixes are found as 6%, 4.5%, and 4.5% and similarly OBC are found as 5% for modified SMA mixes and 4% for modified BC and DBM mixes with polyethylene at different concentration. OPC has been found as 1.5% of polyethylene for all types of modified mixes with fly ash and slag. From graphs it is found that bituminous mixes with fly ash and slag have same OBC as conventional mixes, resulting higher stability values. But OBC values decrease for BC and DBM and increases for SMA in case of polymer modified bituminous mixture with slag and fly ash in comparison to OBC of modified bituminous mixture with stone dust.

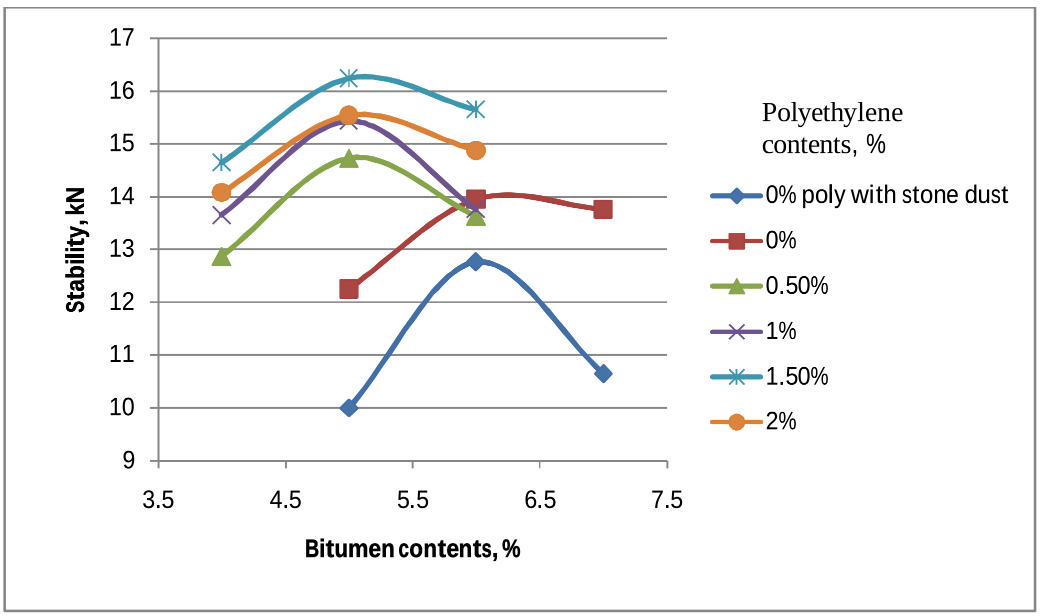


Fig. 5.20 Variations of Marshall Stabilities of SMA with different binder and polyethylene contents

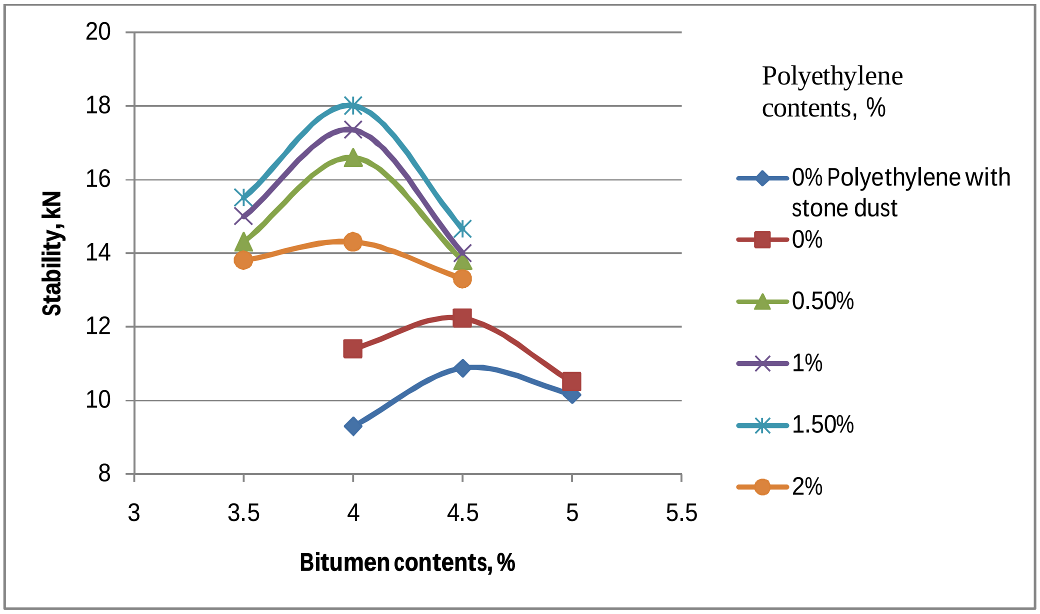


Fig. 5.21 Variations of Marshall Stabilities of BC with different binder and polyethylene contents

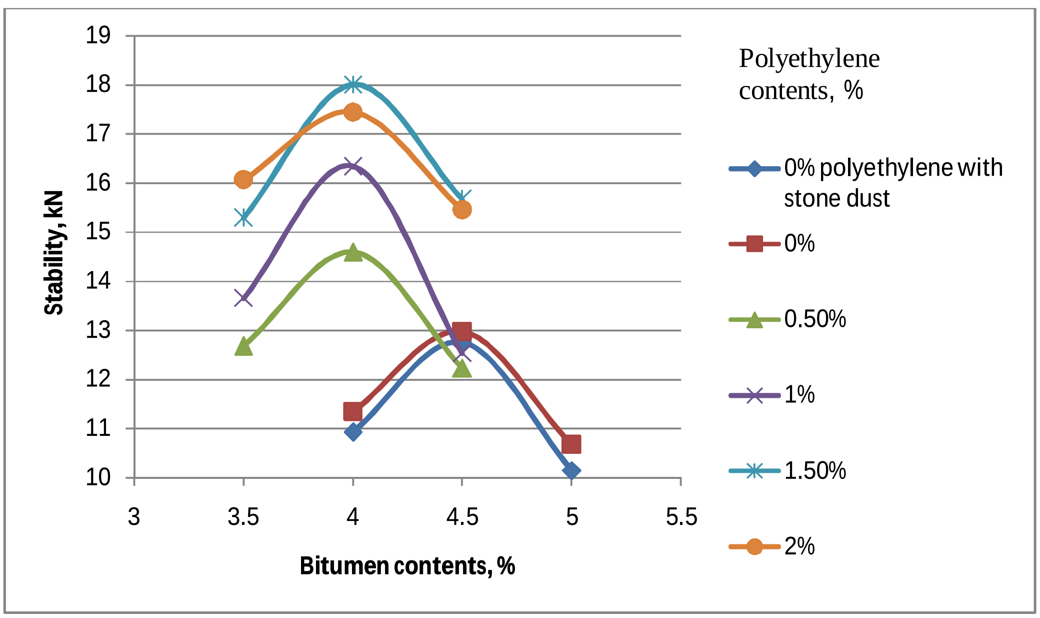


Fig. 5.22 Variations of Marshall Stabilities of DBM with different binder and polyethylene contents

5.4.2 Flow values

It is observed from graphs that all the mixes with fly ash and slag with or without polyethylene possess has less flow values than that of conventional mixes.

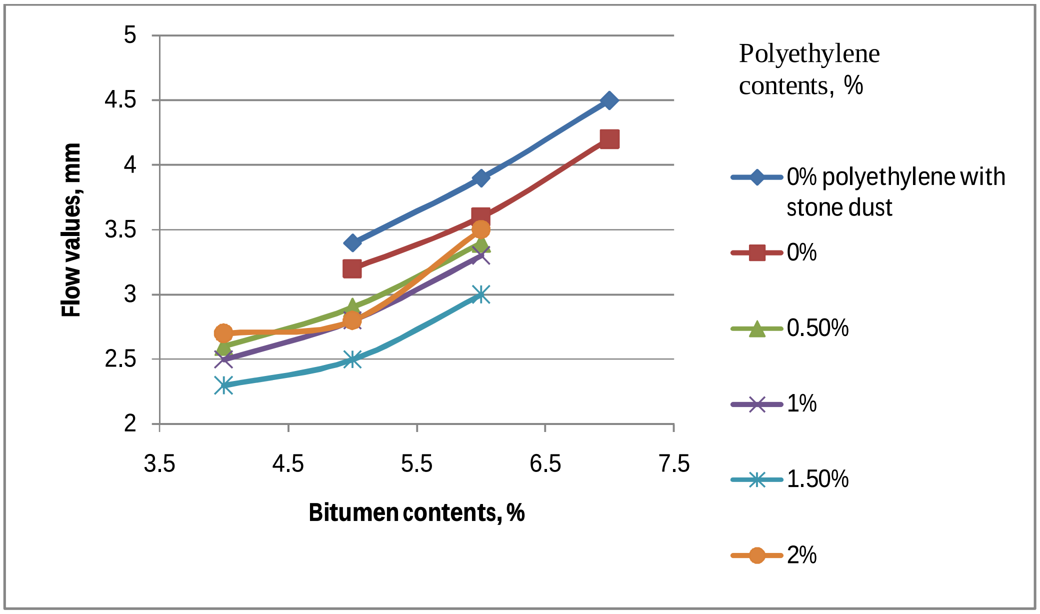


Fig. 5.23 Variations of flows value of SMA with different binder and polyethylene contents

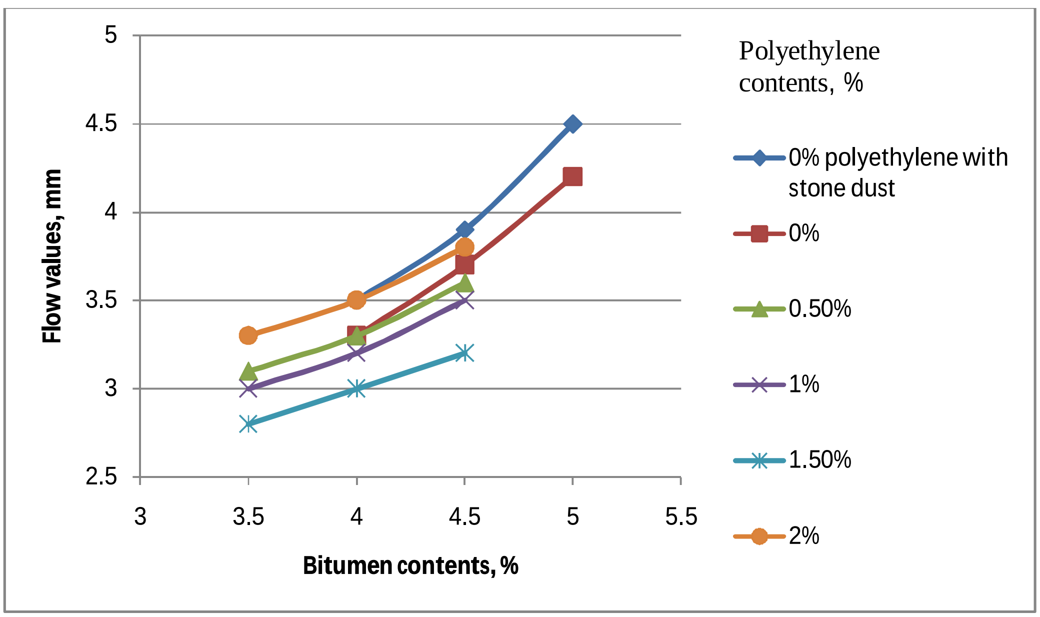


Fig. 5.24 Variations of flows value of BC with different binder and polyethylene contents

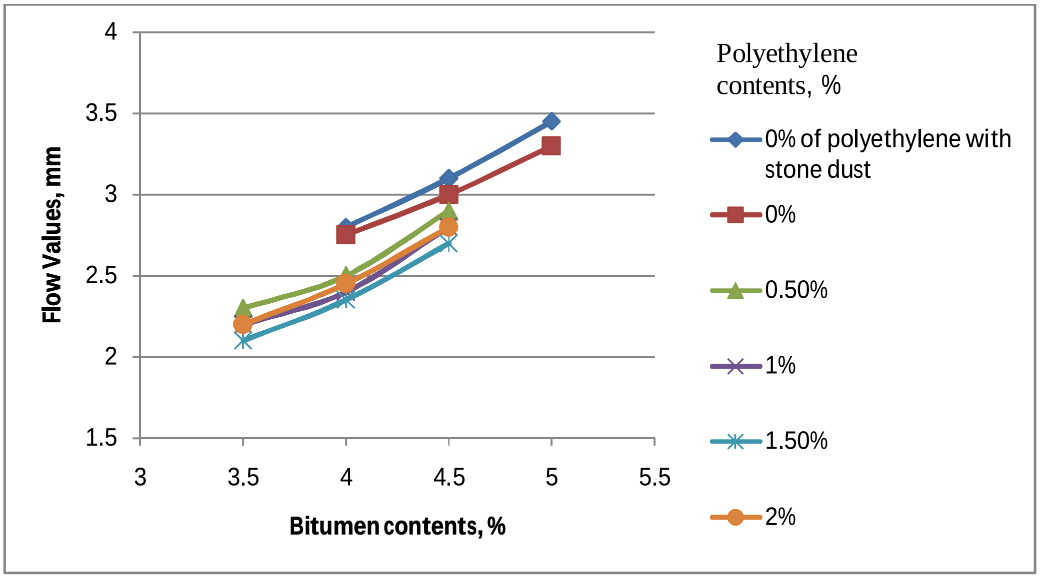


Fig. 5.25 Variations of flows value of DBM with different binder and polyethylene contents

5.4.3 Unit weight

It is observed that unit weight is increasing with increase in binder concentration up to certain binder content e.i, OBC; then start to decrease. With increase in polyethylene concentration in case mixes with fly ash and slag, its value decreases than conventional mix. The mix with fly ash and slag without polyethylene posses less unit weight than that of conventional mixes.

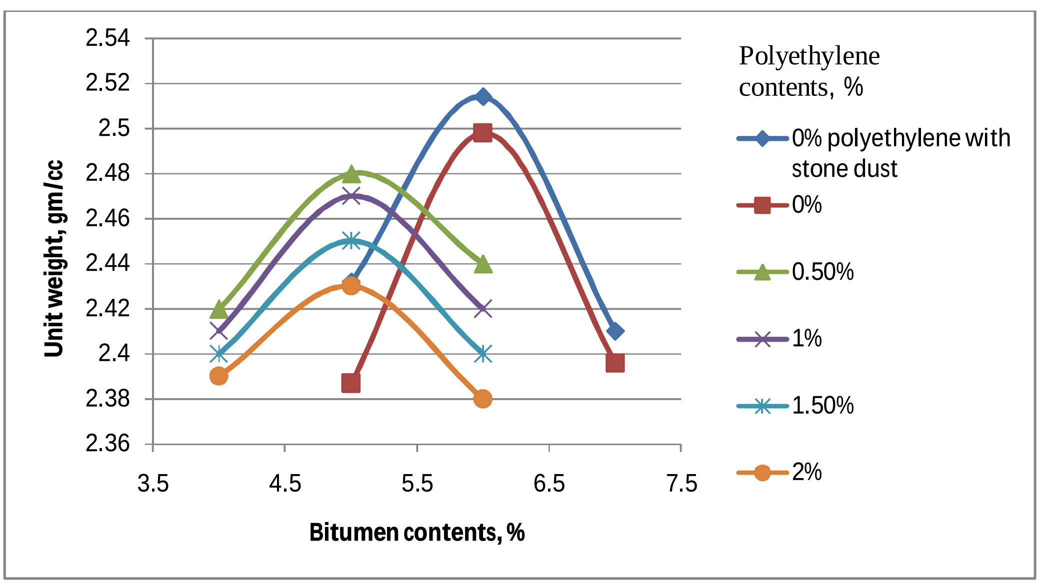


Fig. 5.26 Variations of unit weight values of SMA with different binder and polyethylene contents

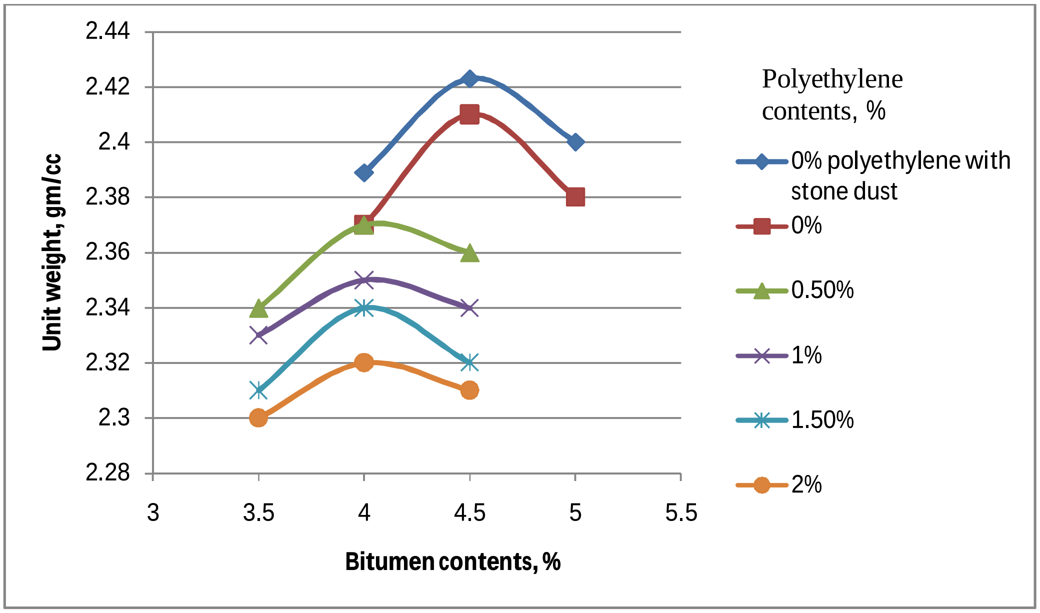


Fig. 5.27 Variations of unit weight values of BC with different binder and polyethylene contents

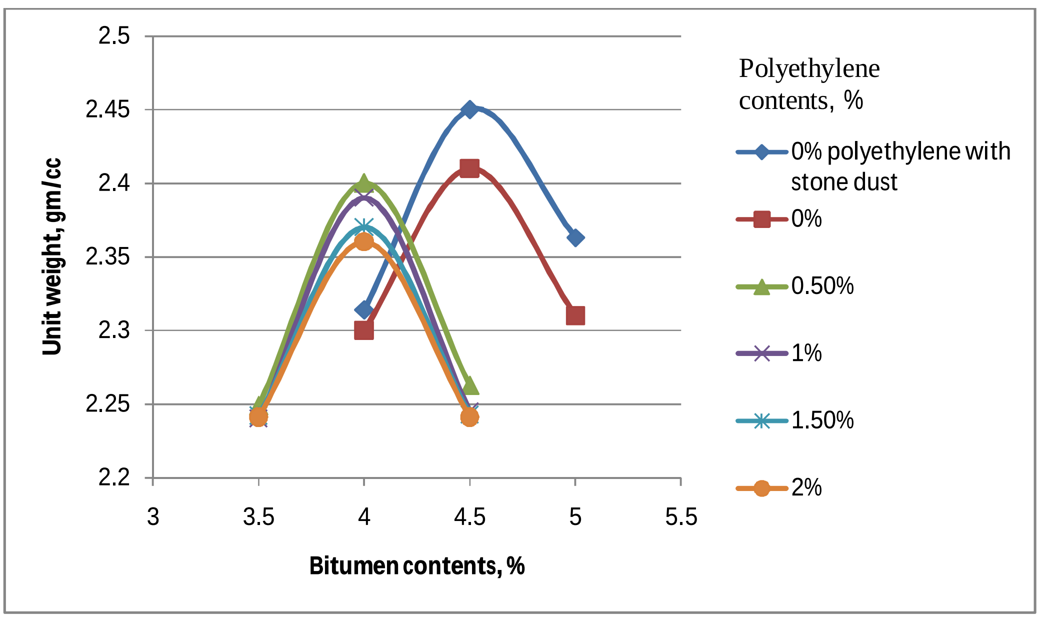


Fig. 5.28 Variations of unit weight values of DBM with different binder and polyethylene contents

5.4.4 Air void (VA)

It is observed that with increase in binder content air void decreases. But with addition of polyethylene to mix with fly ash and slag the air void increases than that of both conventional mixes and mixes with fly ash and slag.

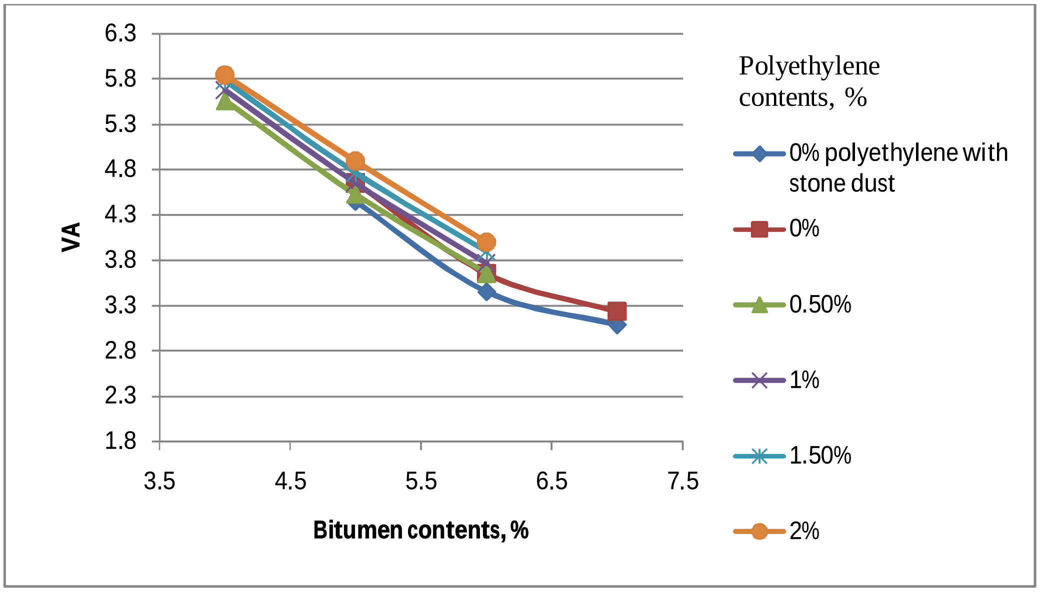


Fig. 5.29 Variations of VA values of SMA with different binder and polyethylene contents

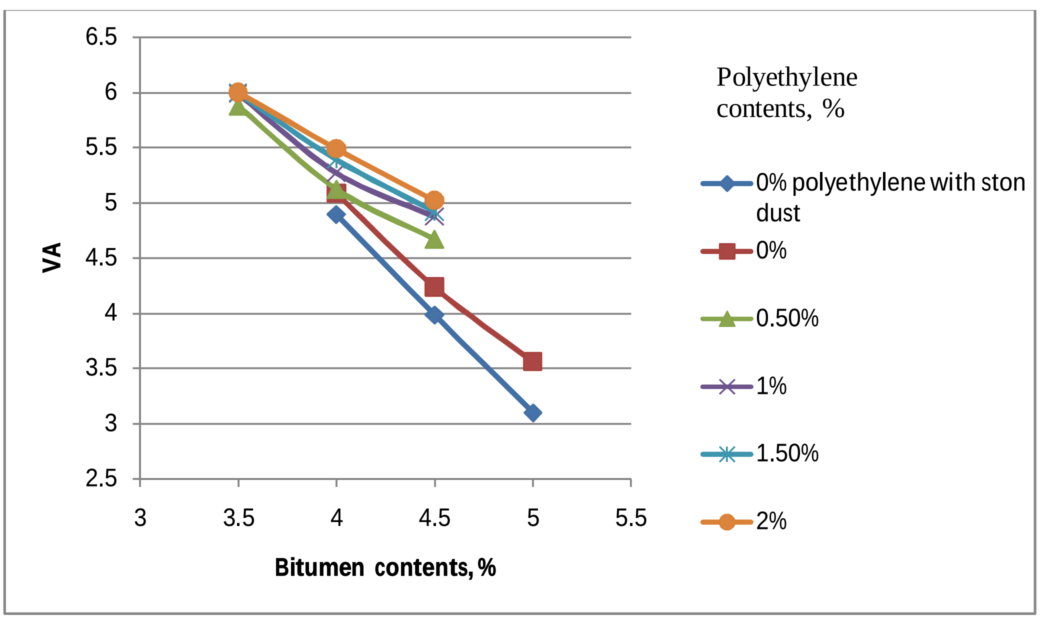


Fig. 5.30 Variations of VA values of BC with different binder and polyethylene contents

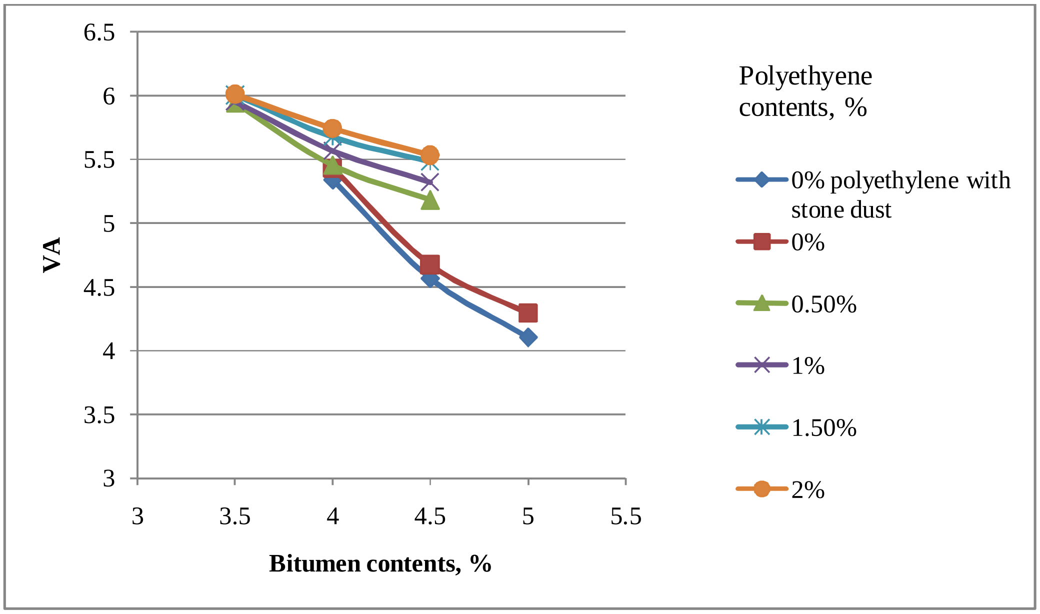


Fig. 5.31 Variations of VA values of DBM with different binder and polyethylene contents

5.4.5 Void in mineral aggregate (VMA)

It is observed that first VMA decreases and then it increases at sharp rate with increase in bitumen concentration in mixes. Variation of VMA values with different binder contents and with different polyethylene contents are shown in graphs below. From the graphs it is observed that with and without addition of polyethylene to mix with fly ash and slag the VMA values increases than that of conventional mixes.

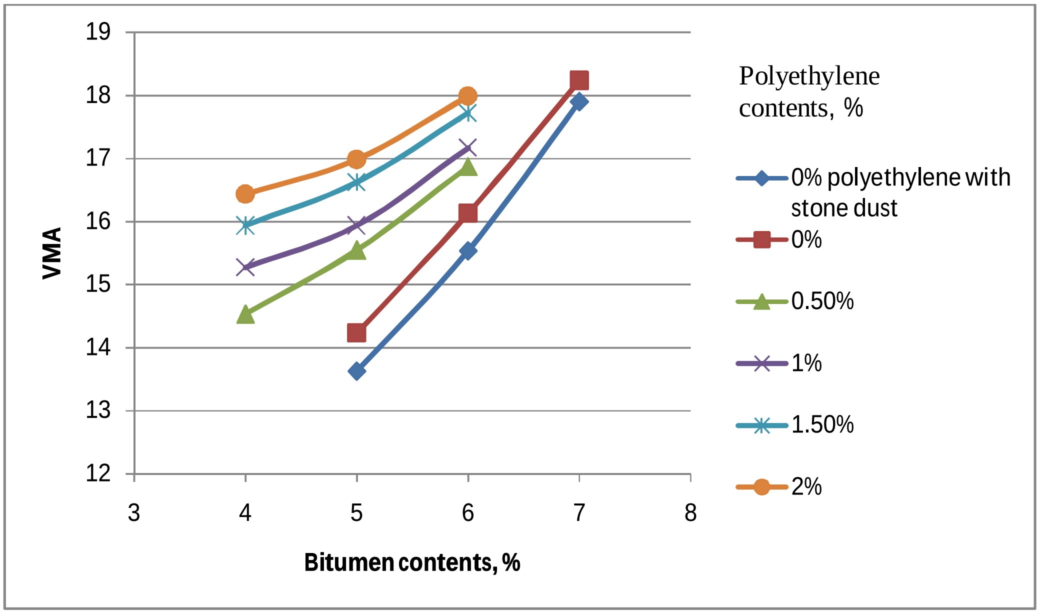


Fig. 5.32 Variations of VMA values of SMA with different binder and polyethylene content

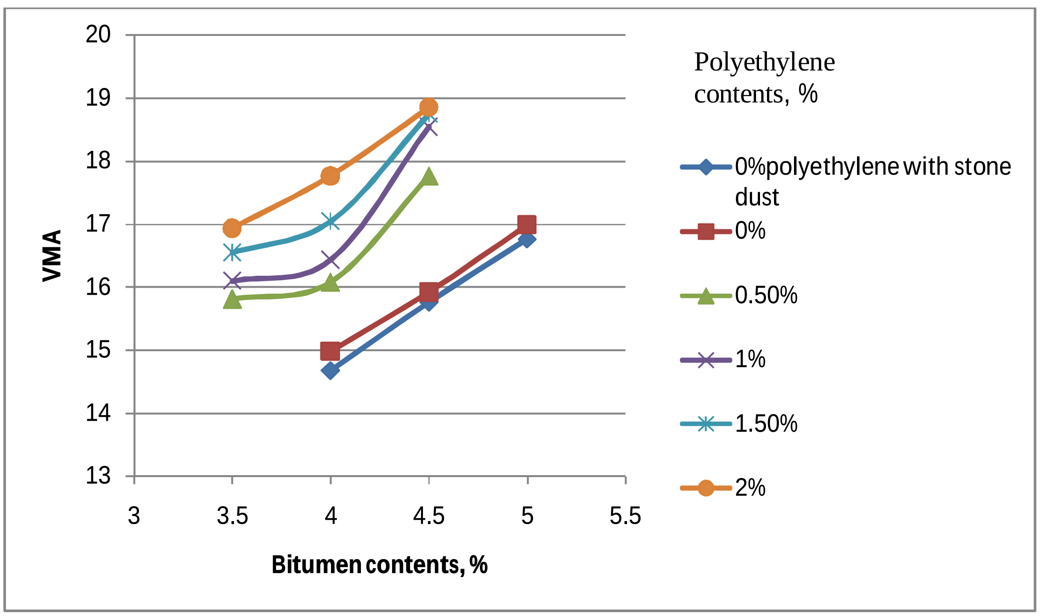


Fig. 5.33 Variations of VMA values of BC with different binder and polyethylene content

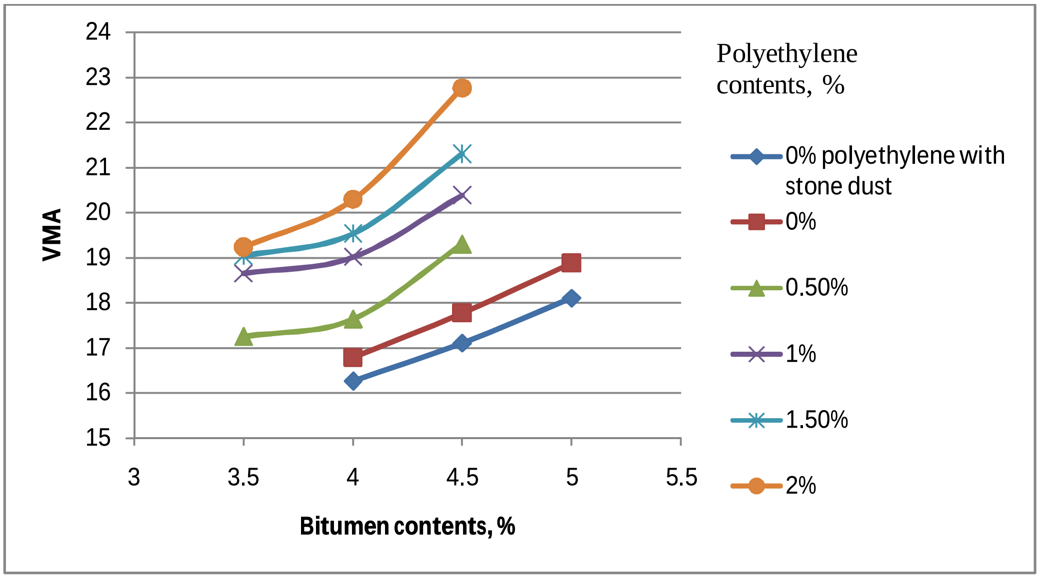


Fig.5.34 Variations of VMA values of DBM with different binder and polyethylene content

5.4.6 Void filled with bitumen (VFB)

It is observed that VFB values of different mixes increase at sharp rate with increase in bitumen concentration. From these graphs it is observed that with addition of polyethylene to mixes with fly ash and slag the VFB increases than that of both conventional mixes and mix with fly ash and slag without polyethylene.

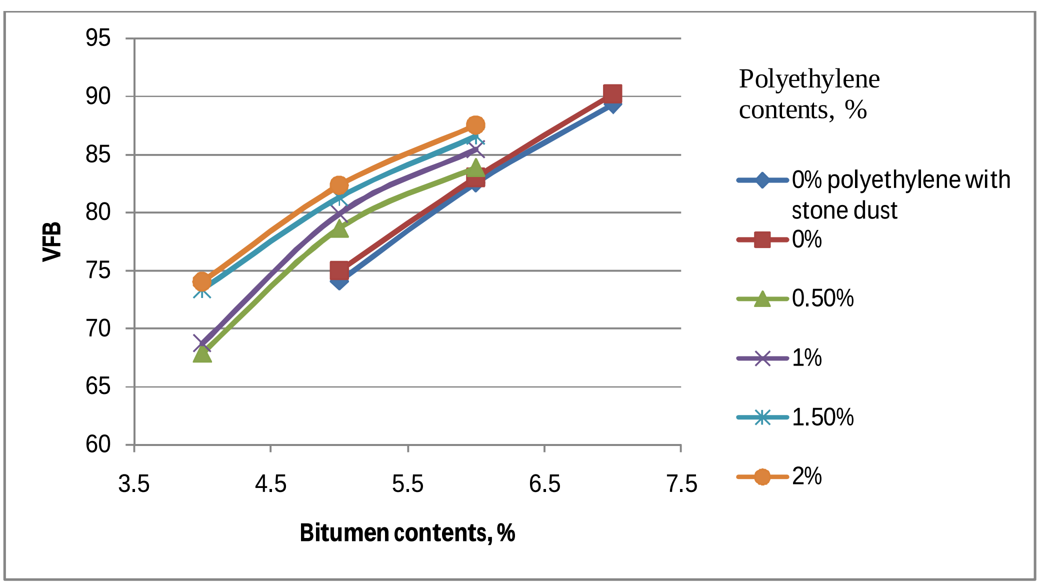


Fig. 5.35 Variations of VFB values of SMA with different binder and polyethylene content

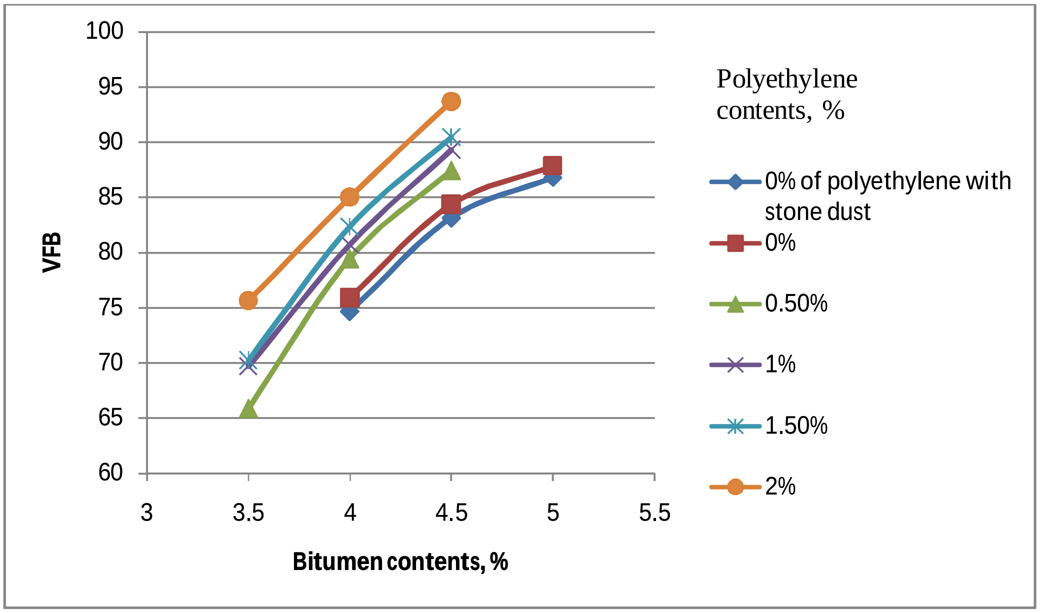


Fig. 5.36 Variations of VFB values of BC with different binder and polyethylene content

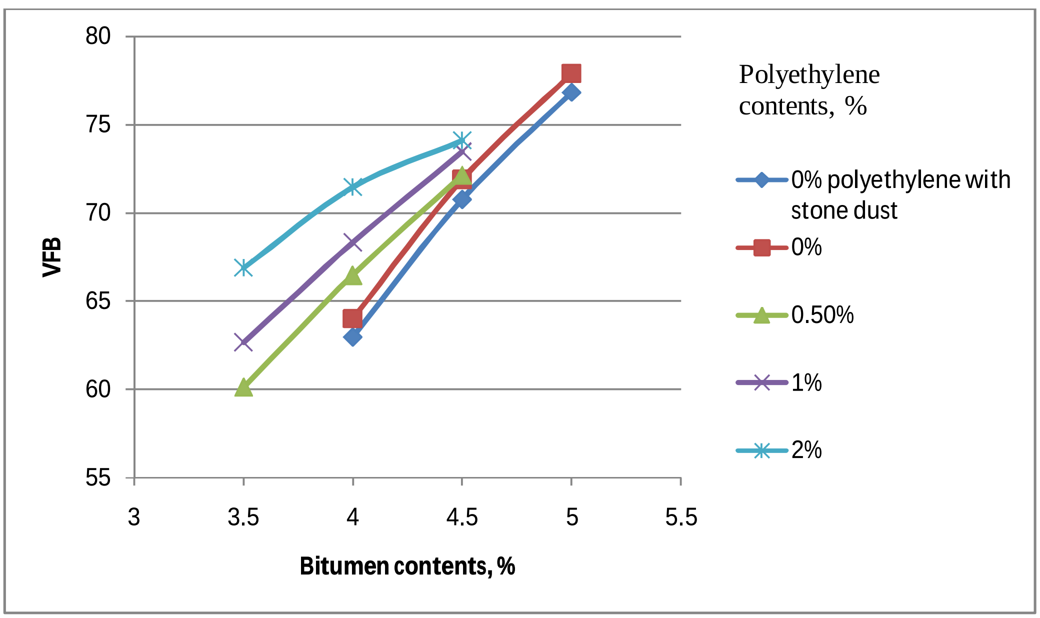


Fig. 5.37 Variations of VFB values of DBM with different binder and polyethylene content

Table 5.5 Optimum binder contents

Types of mixes with fly ash and slag	Optimum polyethylene content (%)	Optimum binder content (%)
SMA without polyethylene	0%	6%
SMA with polyethylene	1.5%	5%
DBM without polyethylene	0%	4.5%
DBM with polyethylene	1.5%	4%
BC without polyethylene	0%	4.5%
BC with polyethylene	1.5%	4%

Table 5.6 Comparisons of stabilities at OBC

Types of mix with fly ash and slag	Stability(kN)
SMA without polyethylene	13.94
SMA with polyethylene	16.24
DBM without polyethylene	12.98
DBM with polyethylene	18
BC without polyethylene	14.23
BC with polyethylene	18

Table 5.7 Comparisons of flow values at OBC

Types of mix with fly ash and slag	Flow(mm)
SMA without polyethylene	3.6
SMA with polyethylene	2.5
DBM without polyethylene	3
DBM with polyethylene	2.35
BC without polyethylene	3.7
BC with polyethylene	3

5.4.7 Retained stability

Retained stability is calculated for SMA, BC, and DBM mixes for both of with polyethylene and without polyethylene with fly ash and slag. It is observed for both the cases that the addition of fly ash and slag to conventional mix and again addition of polyethylene to the mixture with fly ash and slag the retained stability value increases. It means resistance to lose of stability due to stripping in mixes increases with addition of polyethylene and also by addition of fly ash and slag. BC mixes with polyethylene result highest retained stability followed by SMA mixes with polyethylene and then DBM mixes with polyethylene with fly ash and slag.

TABLE-5.8 RETAINED STABILITY OF SMA, BC, AND DBM WITH AND WITHOUT POLYETHYLENE WITH FLY ASH AND SLAG

Types of mix with fly ash and slag	Avg. stability after half an hour in water at 60 °c	Avg. stability after 24 hours in water at 60 °c	Avg. retained Stability, in %	Design requirement
SMA without polyethylene	13.94	10.87	74.98	Minimum 75% (as per MORTH Table 500-17)
SMA with polyethylene	16.24	13.28	80.8	
DBM without polyethylene	12.98	10.31	77.48	
DBM with polyethylene	18	14.72	81.78	
BC without polyethylene	14.23	11.51	75.9	
BC with polyethylene	18	14.48	84.45	

5.5 Drain down test

Drain down test is carried out for both SMA and BC for both of following cases;

(a) Stone dust with and without polyethylene and

(b) Fly ash and slag with and without polyethylene.

From test results it is observer that the drain down effect is not significant for un-compacted conventional mix samples. There is no drain down for both cases further with addition of polyethylene to the mixes at their OPC and OBC.

Table 5.9 Drain down of mixes without polyethylene

Mixes with stone dust	**Drain down value (%)**
SMA	1.8
BC	1.2
Mixes with fly ash and slag	**Drain down value (%)**
SMA	1
BC	0.8

Table 5.10 Drain down of mixes with polyethylene

Mixes with stone dust	**Drain down value (%)**
SMA	0
BC	0
Mixes with fly ash and slag	**Drain down value (%)**
SMA	0
BC	0

5.6 Static indirect tensile strength test

Static indirect tensile test of bituminous mix is used to measure the indirect tensile strength (ITS) of the mix which helps to find out the resistance to thermal cracking of a given mix. The static indirect tensile tests are carried out on SMA, DBM and BC mixes prepared at their OBC and OPC for both following cases

(1) With stone dust as filler and,

(2) With fly ash and slag.

The effect of temperature on the indirect tensile strength of mixes with and without polyethylene is also studied.

5.6.1 Effect of polyethylene on static indirect tensile strength

By addition of polyethylene the indirect tensile strength of mix increases than that of conventional mix. Again it results higher value of indirect tensile strength after replacement of some gradation of fine aggregates by slag and using fly ash as filler, than conventional mix. From the graphs it is observed that with addition of polyethylene to the mixes with fly ash and slag also gives higher value of indirect tensile strength than both of conventional mixture and mixture with fly ash and slag.

5.6.2 Effect of temperature on static indirect tensile strength

Figures show the variations of indirect tensile strength with temperature for all types of mixes. It is seen that the ITS value decreases with increase in temperature but when polyethylene is added to the mix it increases. The BC with polyethylene mixes has the highest indirect tensile strength than SMA, than DBM for both the mixes with stone dust as filler and with fly ash and slag. The mixes with fly ash and slag result higher indirect tensile strength than mixes with stone dust as filler.

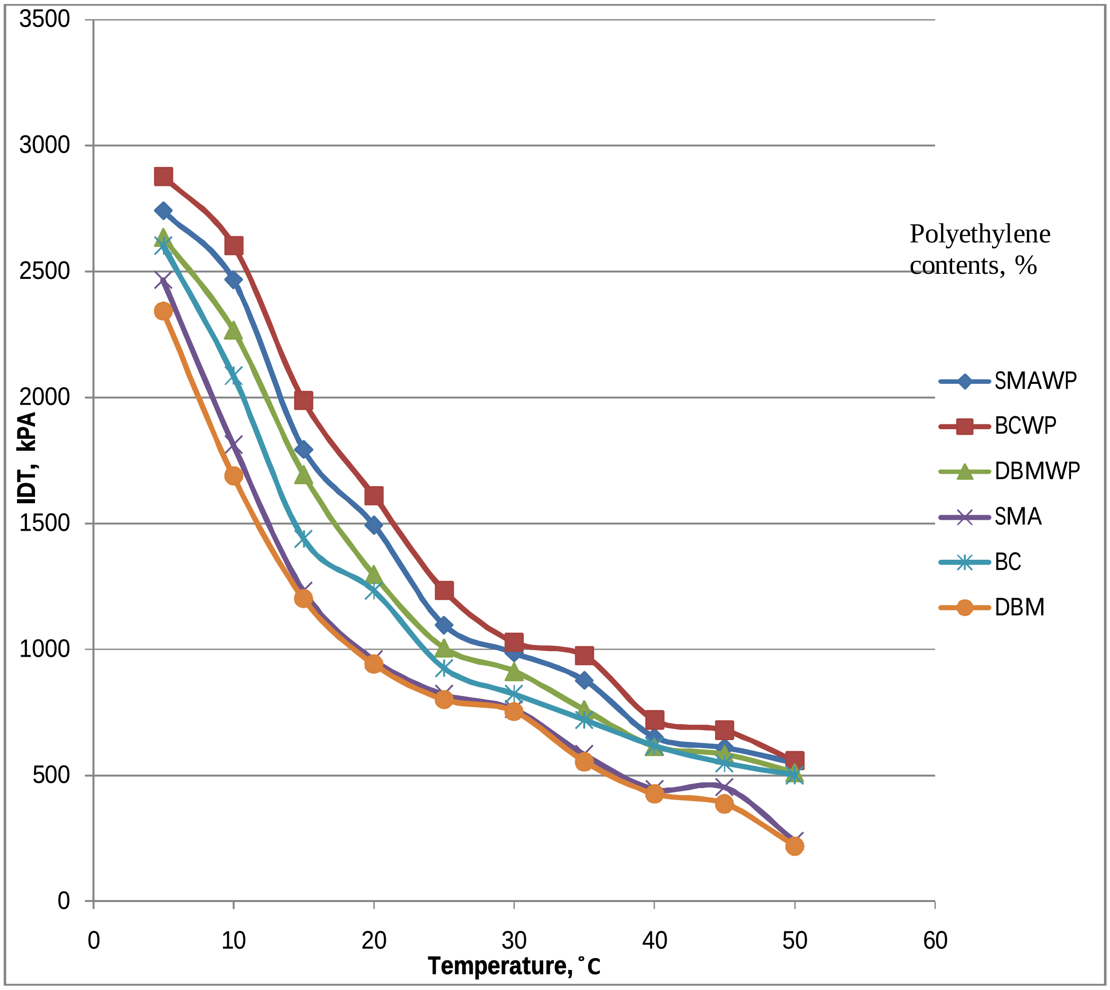


Fig. 5.38 Variation of ITS values of SMA, DBM AND BC with stone dust as filler in different temperatures

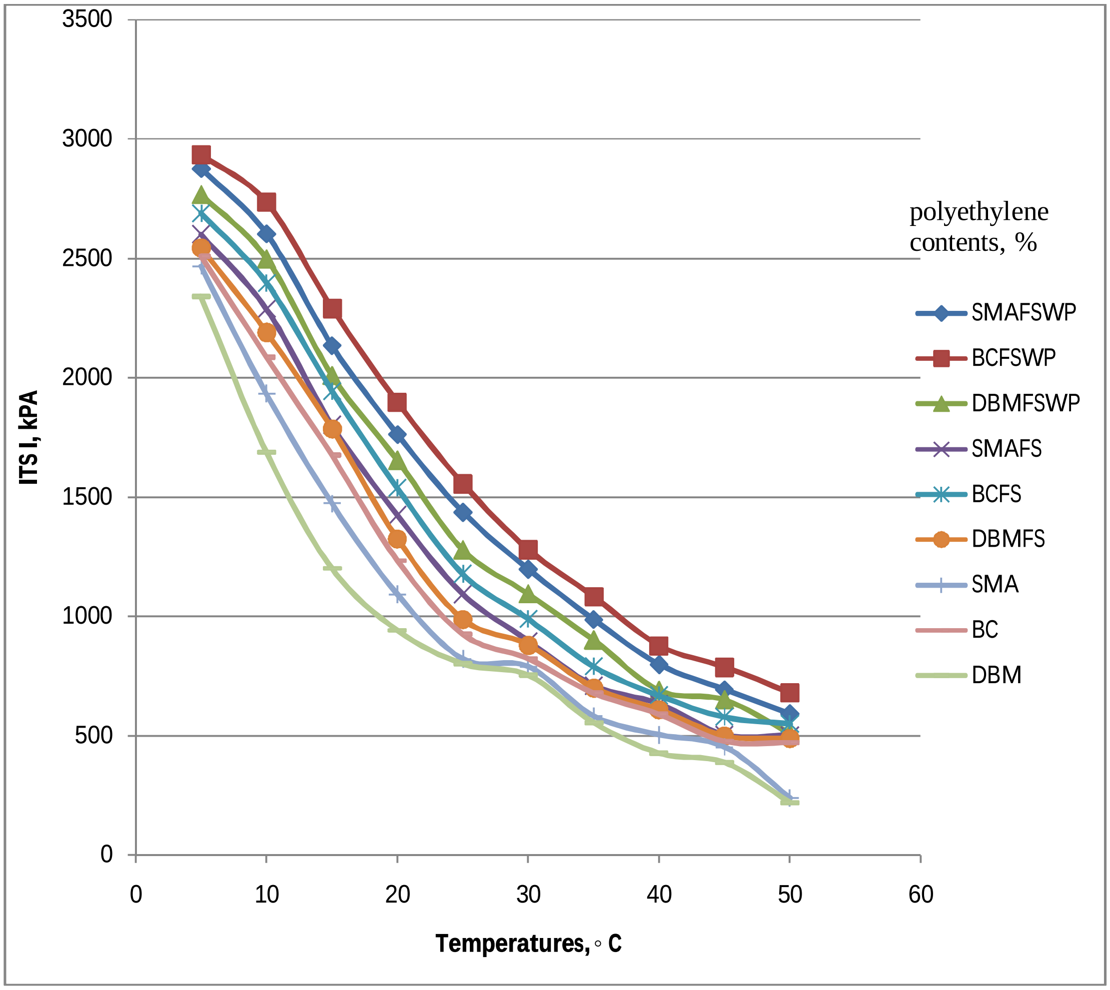


Fig. 5.39 Variation of ITS values of SMA, DBM AND BC with fly ash and slag in different temperatures

5.6.3 Indirect tensile strength ratio

Tensile strength ratio is calculated for SMA, BC, and DBM at their optimum binder content and optimum polyethylene content. It is observed that the addition of polyethylene to the mixture the TSR value increases. It means resistance to moisture susceptibility of mix increases with addition of polyethylene. The mixes with fly ash and slag also results increased value of tensile strength ratio as compared to conventional mixes.

Table 5.11 TSR of mixes with stone dust and with fly ash and slag with and without polyethylene

Types of mixes	Tensile Strength ratio of mixes with stone dust (%)	Tensile strength ratio of mixes with fly ash and slag (%)	Design requirement
SMA without polyethylene	76.81	80.4	Minimum 80% (as per MORTH Table 500-17
SMA with polyethylene	82.14	85.4	
DBM without polyethylene	79.26	81.6	
DBM with polyethylene	84.78	87.2	
BC without polyethylene	79.68	82.7	
BC with polyethylene	87.26	89.1	

5.7 Static creep test

Static creep test is done to measure permanent deformation of bituminous mixes with and without polyethylene when static load is applied. It is analyzed from the test results that deformation of mix decreases by addition of polyethylene at all temperatures. The mixes with fly ash and slag result smaller deformations values than conventional mixes. It is observed that BC mixes with polyethylene give the minimum value of deformation at OPC and OBC than all others for both mixes with stone dust and mixes with fly ash and slag. Graphs have been plotted between;

1. Time and deformation and,
2. Time and strain.

It is observed from the time Vs stain graphs that BC mixes with polyethylene give the minimum strain as compared to other mixes.

5.7.1 Deformations of mixes with stone dust used as filler

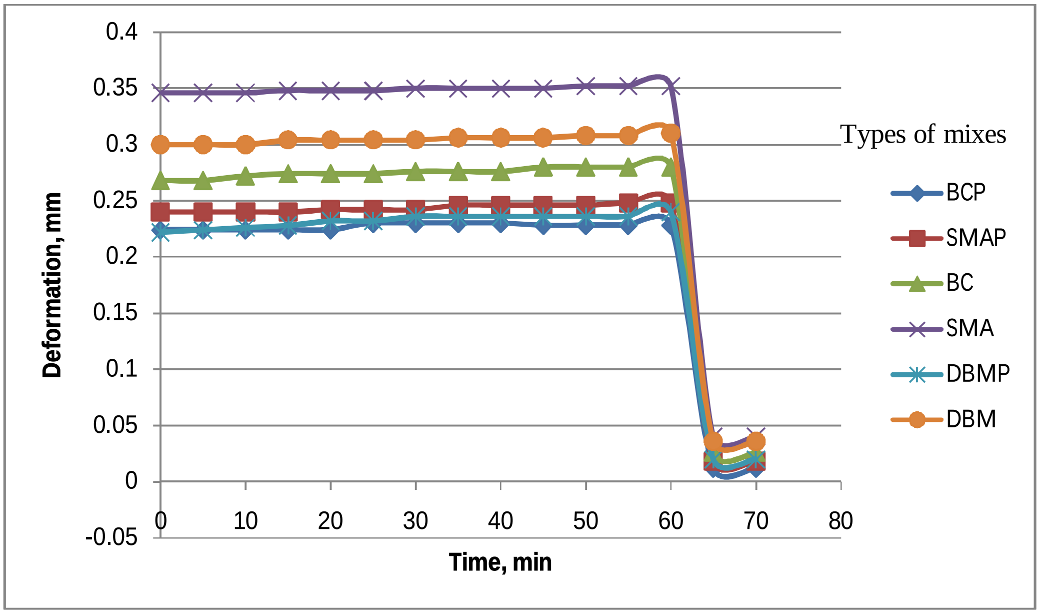


Fig. 5.40 Deformation values at 30 ℃ for SMA, BC, AND DBM

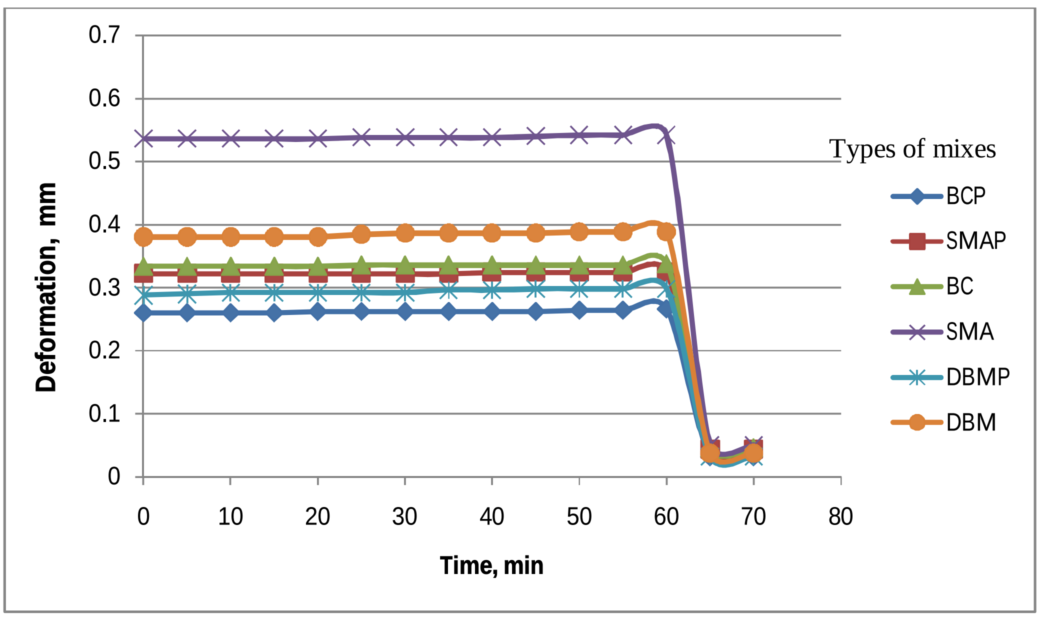


Fig.5.41 Deformation values at 40 ℃ for SMA, BC, AND DBM

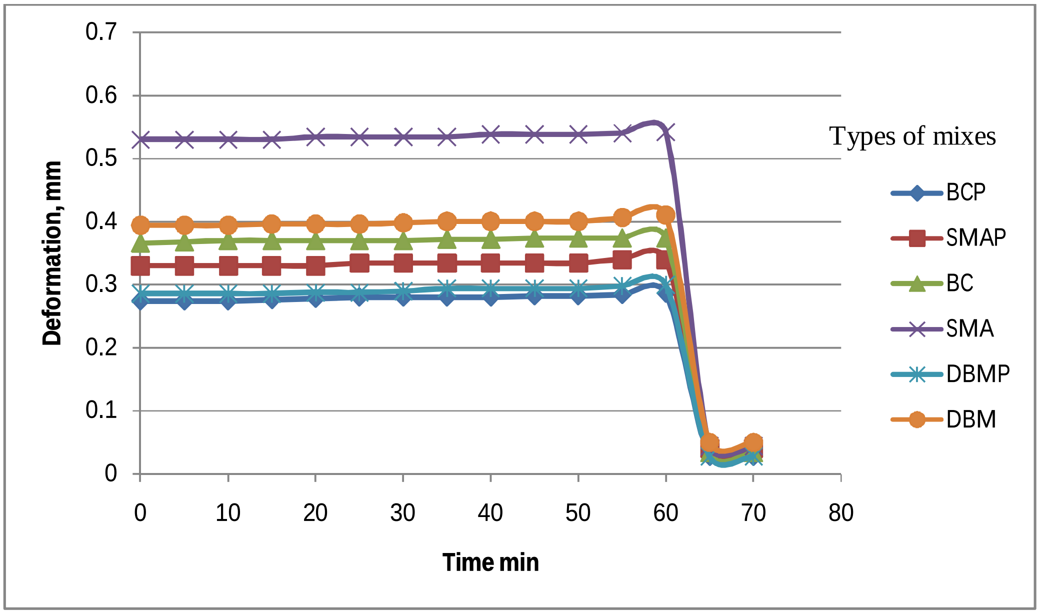


Fig. 5.42 Deformation values at 50 ℃ for SMA, BC, AND DBM

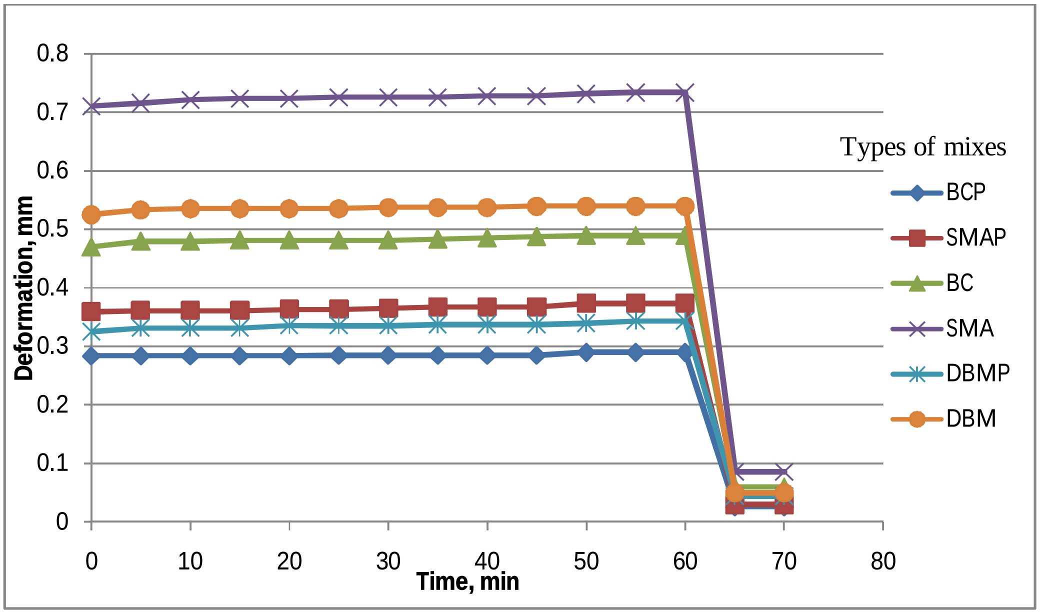


Fig. 5.43 Deformation values at 60 ℃ for SMA, BC, AND DBM

5.7.2 Strain Vs time relationships for mixes with stone dust at all temperatures

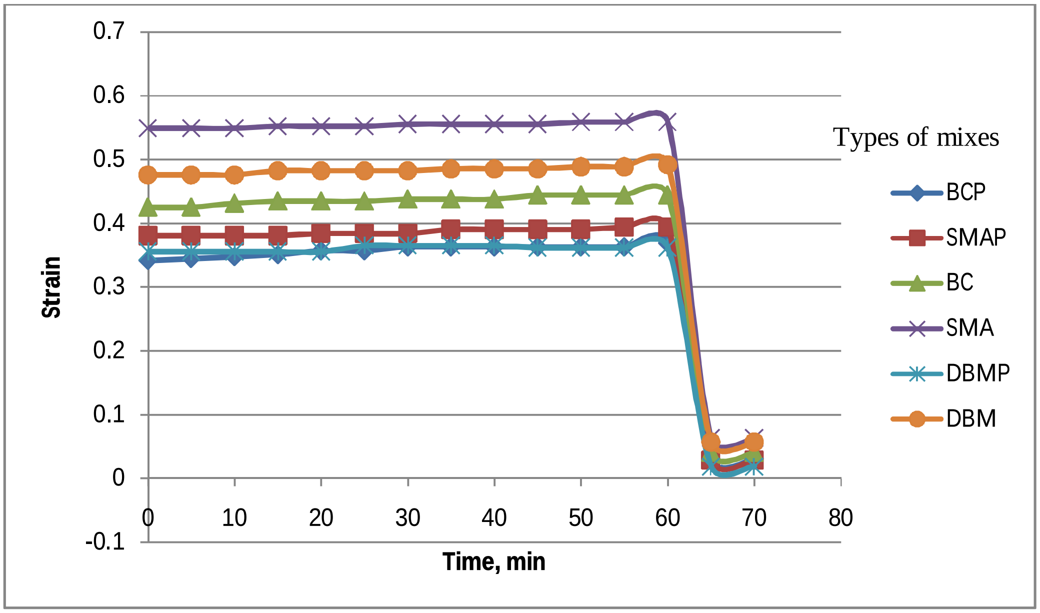


Fig. 5.44 Time Vs strain at 30 ℃ for SMA, BC, and DBM

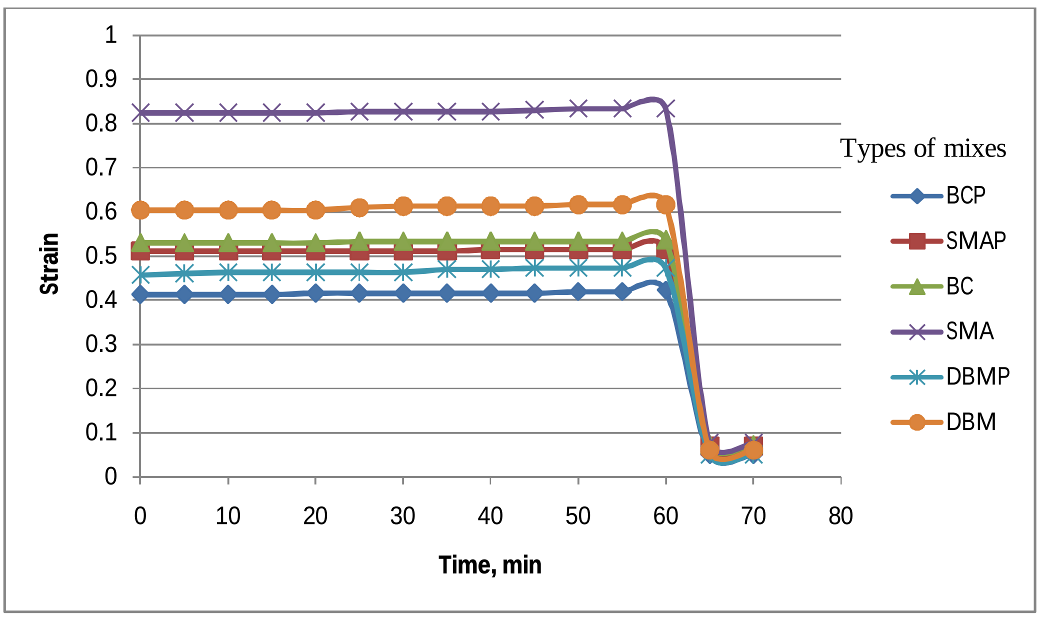


Fig. 5.45 Time Vs strain at 40 ℃ for SMA, BC, and DBM

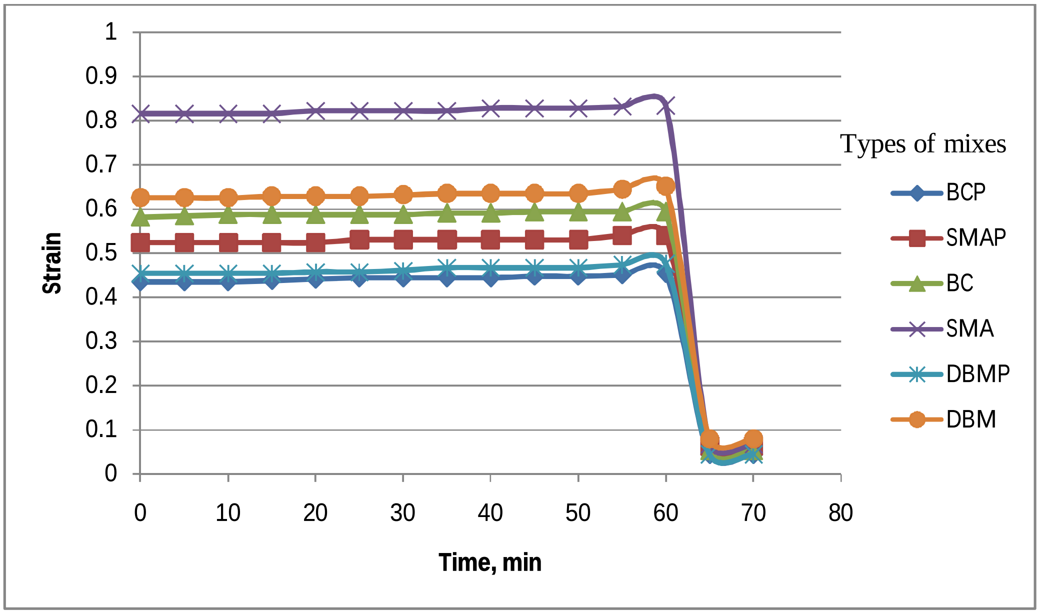


Fig. 5.46 Time Vs strain at 50 ℃ for SMA, BC, and DBM

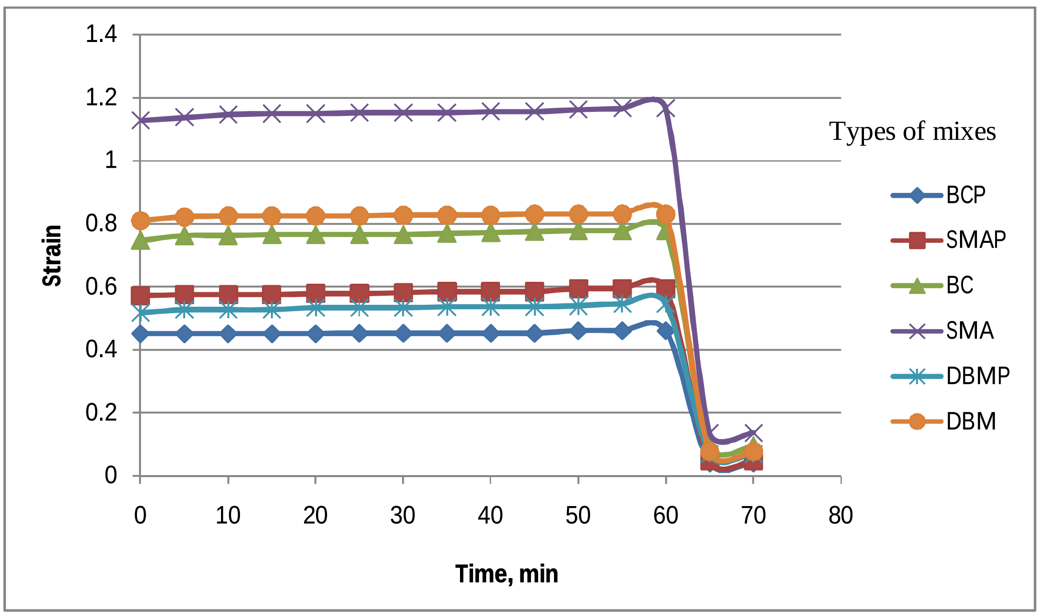


Fig. 5.47 Time Vs strain at 60 ℃ for SMA, BC, and DBM

5.7.3 Deformations of mixes with slag as a part of fine aggregates and fly ash as filler

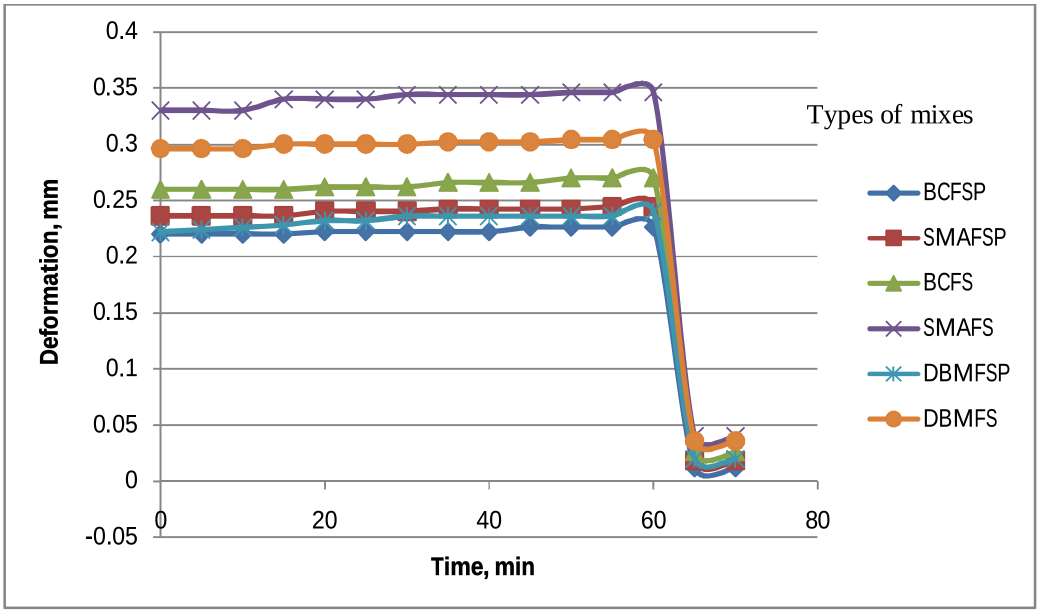


Fig. 5.48 Deformation values at 30 ℃ for SMA, BC, AND DBM

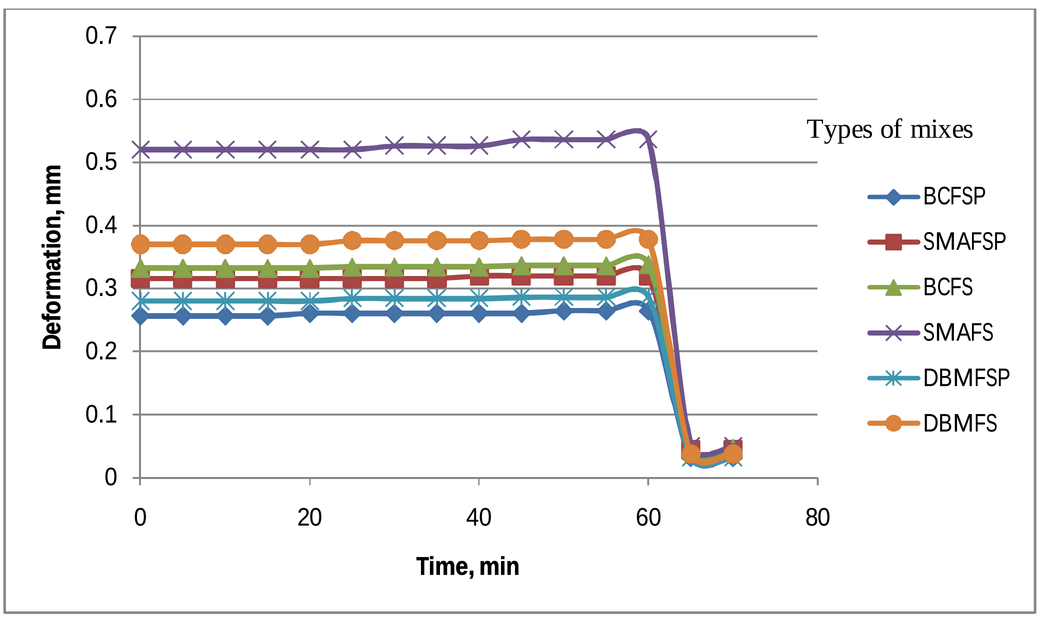


Fig. 5.49 Deformation values at 40 ℃ for SMA, BC, AND DBM

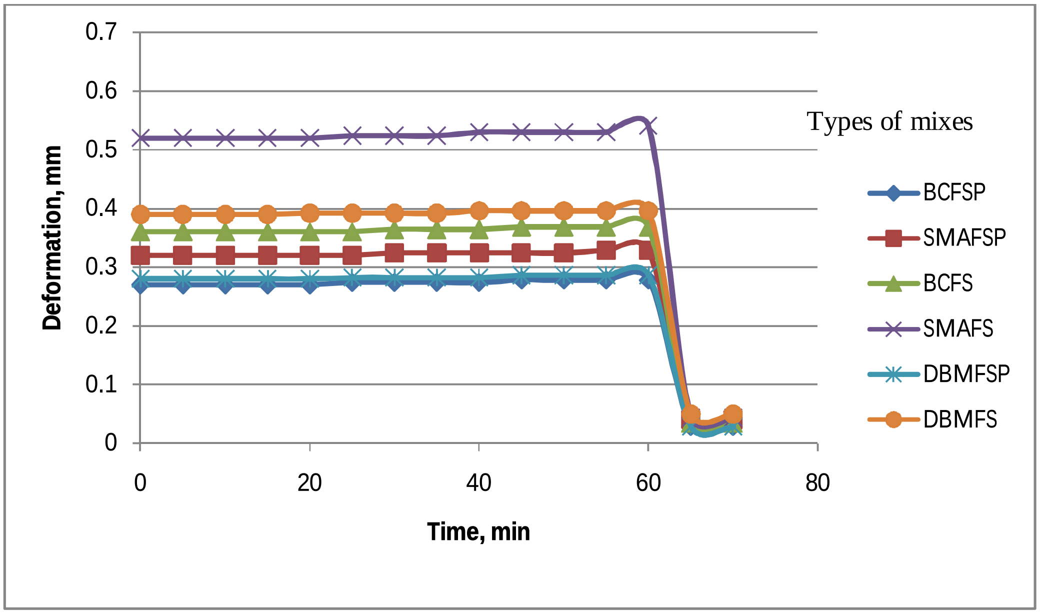


Fig. 5.50 Deformation values at 50 ℃ for SMA, BC, AND DBM

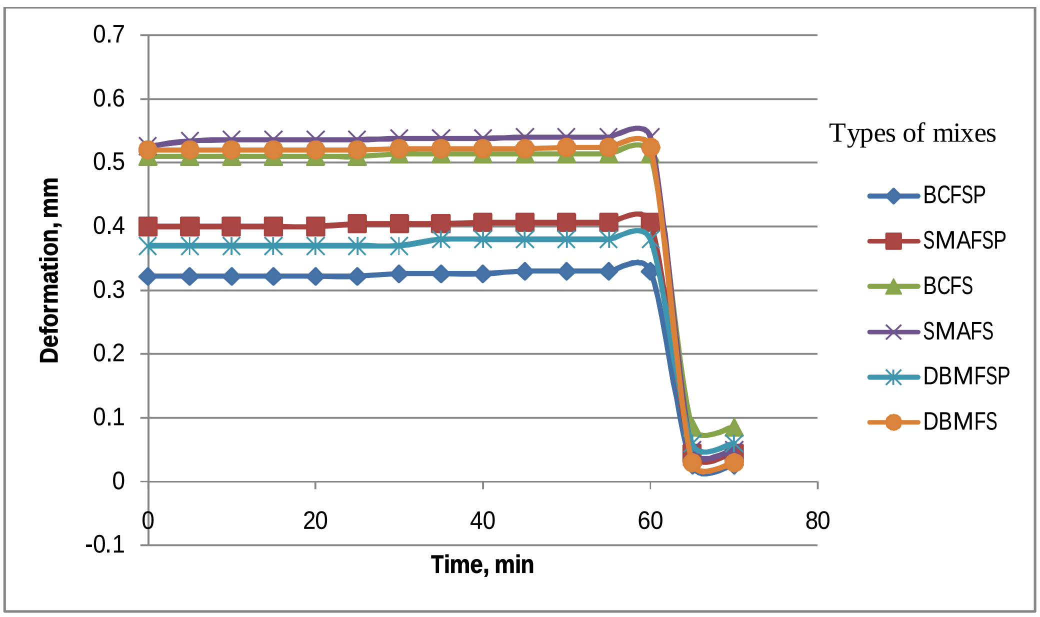


Fig.5.51 Deformation values at 60 ℃ for SMA, BC, AND DBM

5.7.4 Strain Vs time relationships for the mixes with fly ash and slag at different temperatures

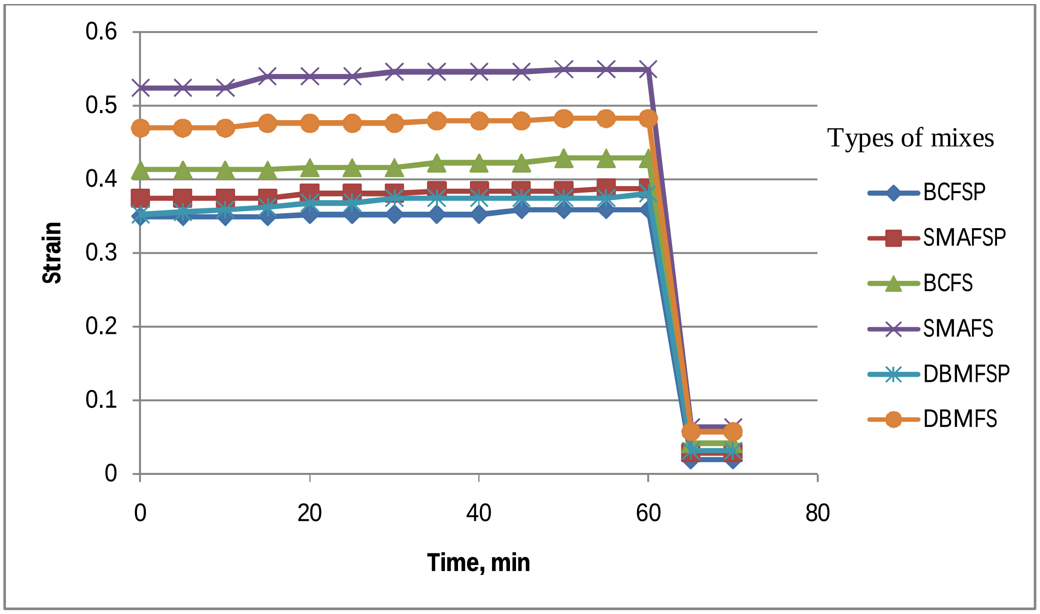


Fig.5.52 Time Vs strain at 30 ℃ for SMA, BC, and DBM

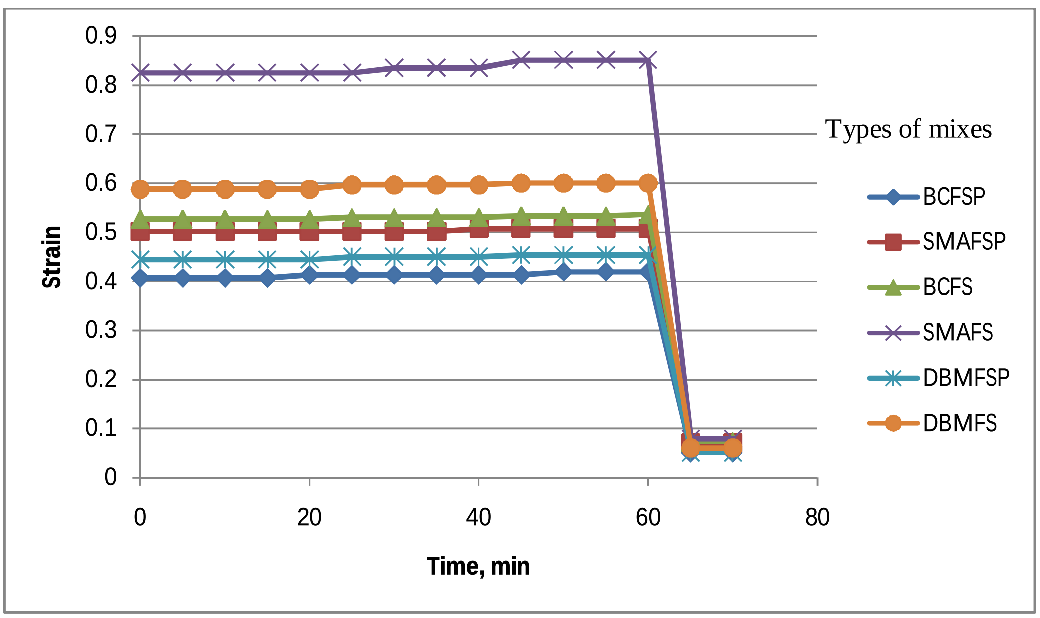


Fig. 5.53 Time Vs strain at 40 ℃ for SMA, BC, and DBM

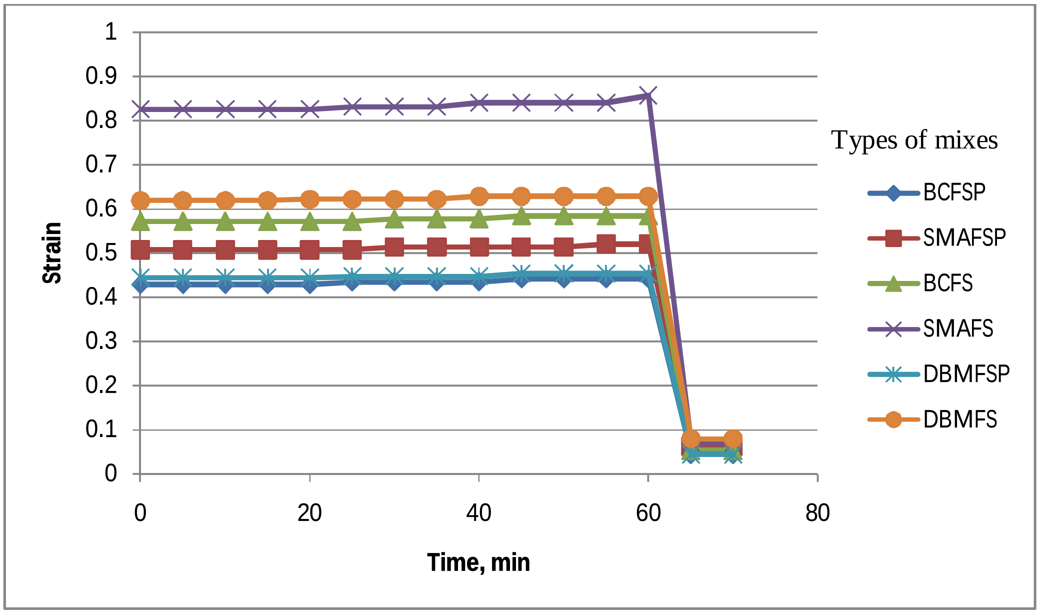


Fig. 5.54 Time Vs strain at 50 ℃ for SMA, BC, and DBM

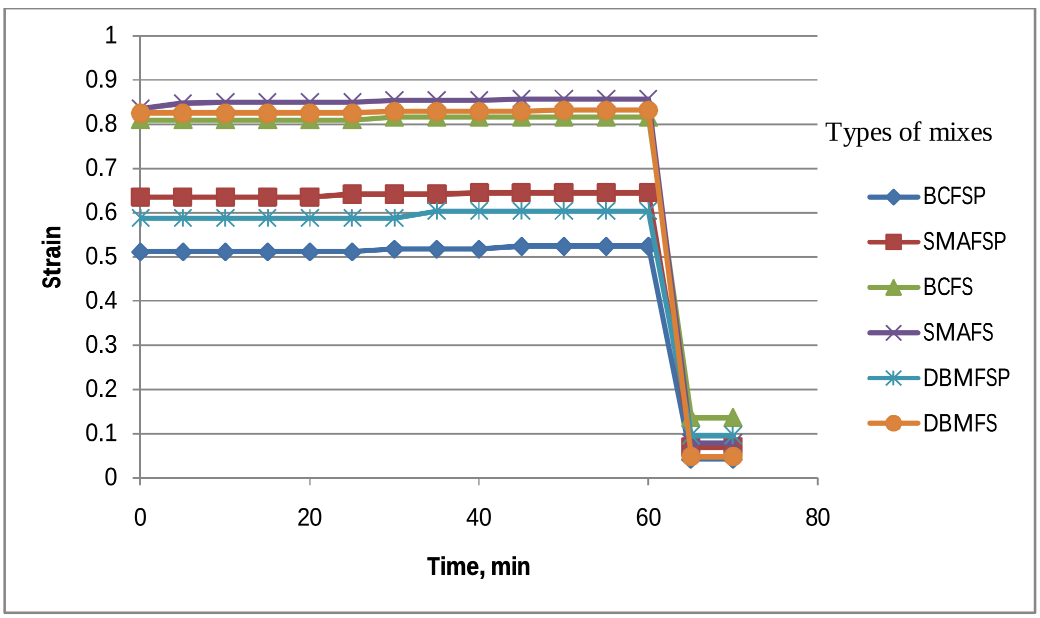


Fig. 5.55 Time Vs strain at 60 ℃ for SMA, BC, and DBM

CHAPTER 6

CONCLUDING REMARKS

In this study, three types of mixes i.e. SMA, DBM and BC are prepared with VG30 grade bitumen used as a binder. The effect of addition of waste polyethylene in form of locally available artificial milk with brand OMFED packets in the bituminous mixes has been studied by varying concentrations of polyethylene from 0% to 2.5% at an increment of 0.5%.

- Using Marshall Method of mix design the optimum bitumen content (OBC) and optimum polyethylene content (OPC) have been determined for different types of mixes. It has been observed that addition of 2% polyethylene for SMA and DBM mixes and 1.5% polyethylene for BC mixes results in optimum Marshall Properties where stone dust is used as filler. But when small fraction of fine aggregates are replaced by granulated blast furnace slag and filler is replaced by fly ash, optimum Marshall Properties for all types of mixes result with only 1.5% polyethylene addition. The OBCs in case of modified SMA, BC and DBM mixes by using stone dust as filler are found 4% and OBCs in case of modified (i) SMA, and (ii) BC, and DBM by using fly ash and slag are found to be 5% and 4% respectively.
- Using the same Marshall specimens prepared at their OPCs and OBCs by using both (i) stone dust as filler and (ii) replacing of stone dust by fly ash and fine aggregate by slag, for test under normal and wet conditions it is observed that the retained stability increases with addition of polyethylene in the mixes, and BC with polyethylene results in highest retained stability followed by DBM with polyethylene and then SMA with polyethylene.
- Addition of polyethylene reduces the drain down effect, though these values are not that significant. It may be noted that the drain down of SMA is slightly more than BC without polyethylene. However, for all mixes prepared at their OPC there is no drain down.

- In general, it is observed that the Indirect Tensile Strength (ITS) value decreases with increase in temperature and for a particular binder, when polyethylene gets added to the mixes the value further increases in both cases. The BC mixes with polyethylene result in highest indirect tensile strength values compared to SMA, followed by DBM.
- It is observed that by addition of polyethylene to the mixture, the resistance to moisture susceptibility of mix also increases. BC with polyethylene results in highest tensile strength ratio followed by DBM mixes with polyethylene and SMA mixes with polyethylene for both cases.
- It is observed from the static creep test that deformation of mix generally decreases by addition of polyethylene at all test temperatures used. The BC mixes with polyethylene result minimum deformation compared to others.

From the above observations it is concluded that use of waste polyethylene in form of packets used in milk packaging locally results in improved engineering properties of bituminous mixes. Hence, this investigation explores not only in utilizing most beneficially, the waste non-degradable plastics, but also provides an opportunity in resulting in improved pavement material in surface courses thus making it more durable.

6.1 Future scope

- Many properties of SMA, BC and DBM mixes such as Marshall Properties, drain down characteristics, static tensile strength, and static creep characteristics have been studied in this investigation by using only VG 30 penetration grade bitumen and polyethylene. However, some of the properties such as fatigue properties, resistance to rutting, dynamic indirect tensile strength characteristics and dynamic creep behavior needed to be investigated.
- In present study polyethylene is added to them mix in dry mixing process. Polyethylene can also be used for bitumen modification by wet mixing process and comparisons made.
- Microstructure of modified bituminous mixture should be observed by using appropriate technique to ascertain the degree of homogeneity.
- Combination of paving mixes formed with other types of plastic wastes which are largely available, wastes to replace conventional fine aggregates and filler an different types of binders including modified binders, should be tried to explore enough scope of finding suitable materials for paving mixes in the event of present demanding situations.

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